LAKESHORE CAPACITY STUDY

FISHERIES

NET PRODUCTIVITY: INDEX OF COTTAGE IMPACT ON FISHERIES

MARCH 1983

Prepared by:
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Ministry of Natural Resources

For:
Ministry of
Municipal Affairs and Housing

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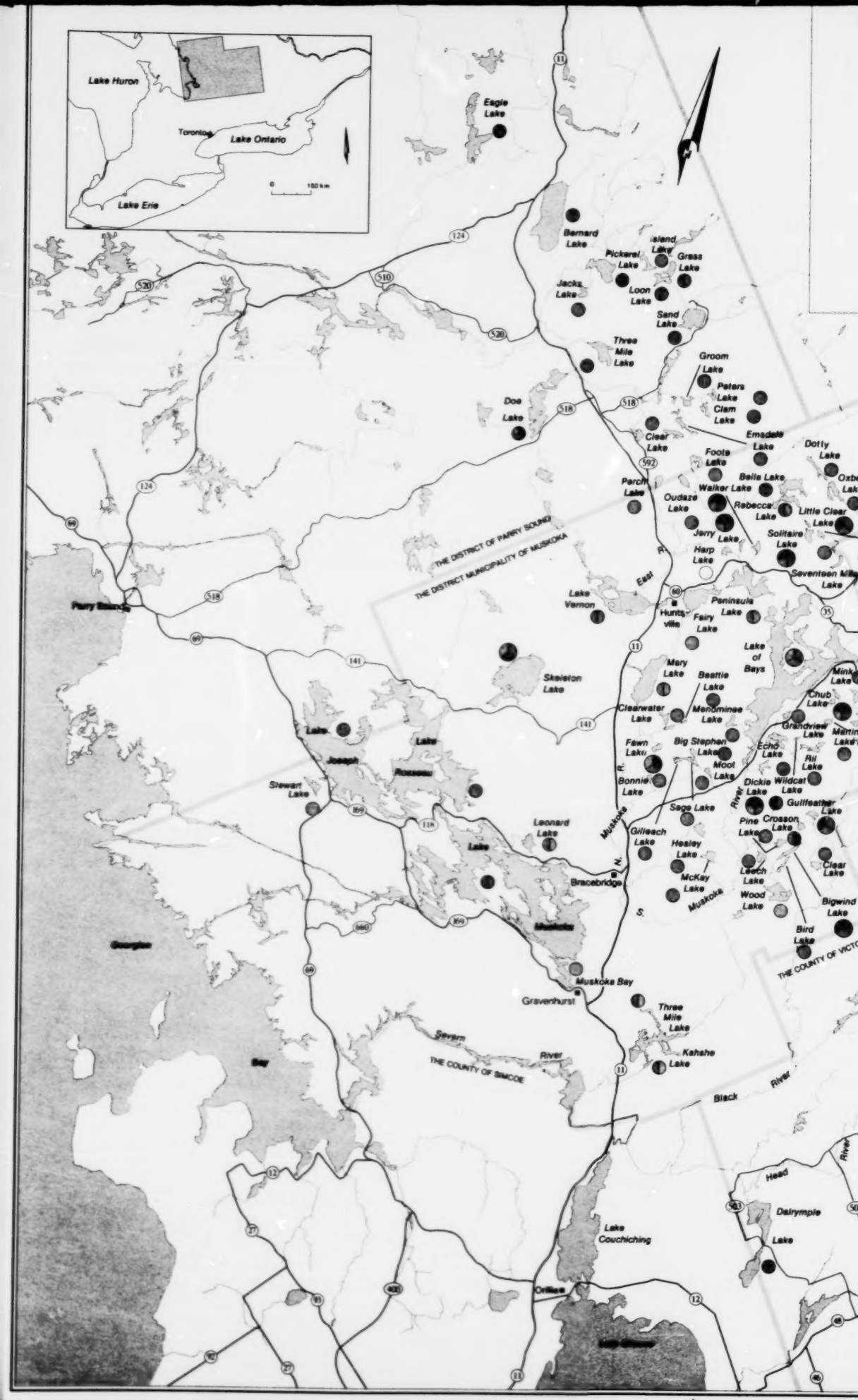
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Clear Lake
McKay Lake
Wood Lake
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Bracebridge
Bird Lake
Muskoka Bay
Gravenhurst
Three Mile Lake
Severn River
THE COUNTY OF SIMCOE
Kahshe Lake
Black River
Head
Dairymple Lake
Lake Couchiching
Orillia

LAKESHORE CAPACITY STUDY

Muskoka-Haliburton Area

0 5 10 15 20 25 30 35

Scale in kilometres

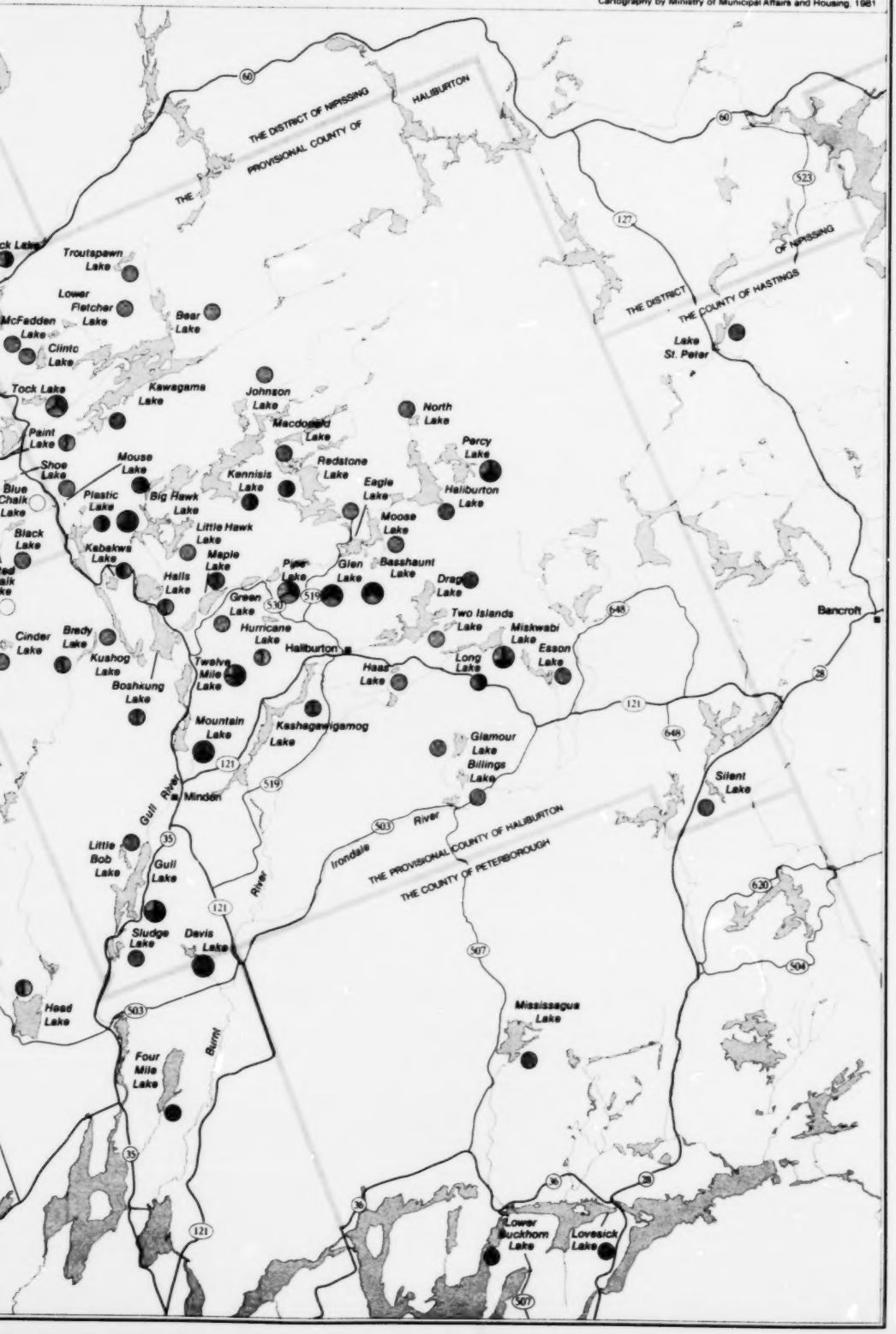
COMPONENTS:

- Wildlife
- Trophic Status
- All
- Microbiology
- Fisheries
- Land Use

The regional survey by the Land Use Component of cottages on portions of lakes is not included

Note: Circle sizes for Cartographic purposes only

Cartography by Ministry of Municipal Affairs and Housing, 1981



LAKESHORE CAPACITY STUDY

FISHERIES COMPONENT

Muskoka-Haliburton Area

0 5 10 15 20 25 30 35

Scale in kilometres

Net Productivity

Littoral

1975 ■ 1978 ■
1976 ■ 1979 ■
1977 ■ 1980 □

NOTE: Symbol sizes for cartographic purposes only

Cartography by Ministry of Municipal Affairs and Housing, 1982

Eagle Lake
Bernard Lake
Island Lake
Pickerel Lake
Grass Lake
Jacks Lake
Loon Lake
Sand Lake
Three Mile Lake
Groom Lake
Peters Lake
Clam Lake
Doe Lake
Clear Lake
Emsdale Lake
Dolly Lake
Foote Lake
Bella Lake
Oxbow Lake
Parch Lake
Walker Lake
Oudaze Lake
Rebecca Lake
Buck Lake
Troutspawn Lake
Jerry Lake
Harp Lake
Solitaire Lake
Lower Fletcher Lake
Seventeen Mile Lake
McFadden Lake
Bear Lake
Lake Vernon
Peninsula Lake
Fairy Lake
Lake of Bays
Tock Lake
Kawagama Lake
Johnson Lake
Macdonald Lake
North Lake
Percy Lake
Halliburton Lake
Skeleton Lake
Mary Lake
Beattie Lake
Mink Lake
Paint Lake
Chub Lake
Shoe Lake
Mouse Lake
Redstone Lake
Clearwater Lake
Menominee Lake
Blue Chalk Lake
Plastic Lake
Big Hawk Lake
Kennisis Lake
Fawn Lake
Big Stephen Lake
Echo Lake
Grandview Lake
Martin Lake
Black Lake
Pine Lake
Glen Lake
Bassbaunt Lake
Drag Lake
Moot Lake
Rill Lake
Kabakwe Lake
Maple Lake
Bonnie Lake
Dickie Lake
Wildcat Lake
Red Chalk Lake
Halls Lake
Green Lake
Sage Lake
Gullfeather Lake
Hurricane Lake
Gilleach Lake
Healey Lake
Brady Lake
Cinder Lake
Kushog Lake
Twelve Mile Lake
Haas Lake
Long Lake
Miskwabi Lake
Esson Lake
McKay Lake
Leech Lake
Clear Lake
Boshkung Lake
Mountain Lake
Kashagawigamog Lake
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Gull Lake
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Davis Lake
Three Mile Lake
Kahshe Lake
Head Lake
Four Mile Lake
Dalrymple Lake
Lake Couchiching
Lake Simcoe
Mississagua Lake
Lower Buckhorn Lake
Lovesick Lake
Lake St. Peter
Silent Lake
Bancroft
Parry Sound
Bracebridge
Muskoka Bay
Gravenhurst
Orillia
Georgian Bay
Severn River
Black River
Head River
Gull River
Burnt River
Ironside River
Mississagua River
Muskoka River
Muskoka Lake
Joseph Lake
Rosseau Lake
Stewart Lake
Leonard Lake
Muskoka Lake
Lake
THE DISTRICT OF PARRY SOUND
THE DISTRICT MUNICIPALITY OF MUSKOKA
THE DISTRICT OF NIPISSING
THE PROVISIONAL COUNTY OF HALIBURTON
THE COUNTY OF VICTORIA
THE COUNTY OF SIMCOE
THE COUNTY OF HASTINGS
THE COUNTY OF PETERBOROUGH

FOREWORD

The Lakeshore Capacity Study was undertaken to provide a planning tool to assist in managing the development of Ontario's inland lakes. Basic to this task was the need to develop an improved understanding of the relationships between cottage development on the lakeshore and selected aspects of the environment. To accomplish these objectives the Ministry of Municipal Affairs and Housing, responsible for the Study, worked with the ministries of the Environment and Natural Resources.

The Muskoka-Haliburton area of central Ontario was chosen as the study area. This area lies within one physiographic region, part of the Precambrian shield, with similar soils and plant communities. The homogeneity reduced the need to account for major natural variations among the lakes and watersheds. Further, the extent of existing development on the lakes varied; permitting an examination of situations extending from no development to "full" development.

The Study involved measurement of the source of the environmental impact, the cottages and their use, and how development affects the indicators of impact: nutrient enrichment; public health; fish, angling and littoral zone; and wildlife and habitat modification. The research findings were linked in a simulation model. The model can predict trends for the various impacts on the watershed.

The Fisheries report examines the relationship of fishing, due to both a change in the number of cottager and non-cottager users, to the kilograms of fish harvested and the amount available for harvest. The major achievement has been the development of quantitative means of estimating fish yield and the amount of harvest permissible before an overfishing condition results.

The objective of this phase of the Lakeshore Capacity Study, to develop a practical planning tool for lake-watershed management, has been achieved. The next step is further testing prior to implementation.

M.H. Sinclair
Chairman
Lakeshore Capacity Study

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Any shortcomings in the application of the advice are the authors' responsibility.

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PEER REVIEW

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SUMMARY

The Net Productivity Study described in this report is one component of the Lakeshore Capacity Study being conducted cooperatively by the Ontario Ministries of Municipal Affairs and Housing, Environment, and Natural Resources to determine the impact of cottage development on water quality, public health, wildlife and sport fisheries. Each component has spent years gathering prerequisite data in the field, analysing results, and developing mathematical models to predict to what extent cottage development may affect the various aspects of the lake environment. These individual models have been combined in a master model in the final, integration phase of the Lakeshore Capacity Study. Two constraints were placed on these models: (1) that information required for the models was to be collected within a designated portion of the Muskoka and Haliburton region; and (2) that the data required to use the model be available in existing records or easily obtainable with a minimum of field work. In the Net Productivity Study, some additional data on other fisheries were taken from the literature to cover a wider range of lake types than was available in the designated areas. These additional data also allowed a comparison between results of the present study and results from the individual lakes subject to more intensive sampling.

Construction of cottages and other facilities which attract people to a lake can affect the fisheries by: (1) changing the water quality and trophic status of the lake; (2) altering or disturbing spawning, nursery and feeding grounds of the fish; and (3) increasing the fishing pressure. The first two effects are being studied in detail by the Trophic Status Component (MOE) and Littoral Zone Sub-component (MNR) respectively. The Net Productivity Component (MNR) also deals with certain aspects of trophic status and with the impact of fishing pressure by cottagers and other anglers.

Briefly stated, the trophic status of a lake is its capacity to sustain the growth and reproduction of plant and animal life. It can be measured and described in terms of water chemistry (total dissolved solids concentrations, phosphorus concentrations, or dissolved oxygen deficits); in biological terms (chlorophyll-*a* concentrations, densities of plankton, or bottom fauna); or in physical terms, such as mean depth or annual temperatures. In the net productivity model, the morphoedaphic index described in the following paragraph, is used as the measure of trophic status. Trophic effects of phosphorus from cottage sewage are not described well by the morphoedaphic index and, hence, these effects will be taken into account in another way in the integration phase of the Lakeshore Capacity Study.

The information on angling effort and catches required for the net productivity model was collected by creel censuses on 46 Muskoka and Haliburton lakes, during the summers of 1975-79 and winters of 1976-79. Sixteen of the lakes were censused in all 4 years, 19 for 2-3 years and 11 for 1 year only. These lakes were selected to give a representative sample of areas, mean depths, total dissolved solids contents, fish species and degrees of cottage development based on information obtained from lake survey records in the MNR District Offices, the Ontario Fisheries Inventory at Queen's Park, and the MNR Land Use Co-ordination Branch. In addition, information from 10 lakes or lake basins selected from the literature was included in the data base.

The term creel, in creel census, refers to the traditional wicker basket in which an angler keeps his or her catch. In the MNR creel censuses records were kept of 1) the type of angler (cottager, commercial guest, day-tripper, etc.), 2) the origin of the angler (local, from Ontario but not local, U.S. resident, etc.), 3) the number of anglers' total time they expected to fish for the day, 4) the number and type of fish caught by the anglers, 5) the number of fish released, and 6) the length and weight of all fish caught, with few exceptions. From the summer of 1977 onwards, scale samples were collected for age determinations.

The net productivity model is an extension of Ryder's morphoedaphic index model which is presently being used in MNR fisheries management to set allowable harvests (quotas). Ryder derived his model by regressing catches from 23 moderately to heavily fished large Canadian lakes against their respective total dissolved solids to mean depth ratios. It takes the form:

$$Y = 1.4 \text{ (total dissolved solids/mean depth)}^{0.45}$$

where Y is the potential fish production for the lake in kilograms per hectare per year and the total dissolved solids in milligrams per litre divided by the mean depth in metres is the morphoedaphic index. As this model indicates, potential fish production increases with increasing dissolved solids but decreases with increasing mean depth. Most of the lakes in the MNR census lie on the Precambrian Shield, have low total dissolved solids, are relatively deep and, consequently, have a limited potential fish production. However, Head, Four Mile, and Dalrymple Lakes lie mostly within limestone plains, have a higher total dissolved solids contents, are relatively shallow and, therefore, tend to be more productive. In essence, the net productivity model compares the kilograms per hectare per year of fish which the anglers catch and keep from a lake with the potential fish production for that lake. This model can be stated mathematically as:

$$P_n = Y/MSY_c$$

where P_n is the net productivity index, Y the weight of fish removed by cottagers and other anglers, and MSY_c the max-

imum sustained yield for the game fish community — all given in kilograms per hectare per year. In this model, the value obtained from Ryder's morphoedaphic index formula is taken as an estimate of MSY_c, and arguments are given to support this interpretation. The Y value is obtained by sequentially solving a series of regression equations based on data collected in creel censuses on 46 lakes in the Muskoka and Haliburton regions of central Ontario during 1975-1979, with some additional data from the literature. In the order in which they are used, these regression equations are (1) summer angling effort per cottage by cottagers on the area of lake; (2) summer effort by anglers other than cottagers on summer effort by cottagers; (3) winter effort by cottagers and others on total summer effort by all anglers; and (4) the harvest by cottagers and other anglers on the morphoedaphic index and the total angling effort for the year. These equations are fitted by least squares with appropriate transformations to the creel census data and the information on area of lake, mean depth, etc. The procedure, whereby a fisheries manager or land use planner would solve them with a pocket calculator, is described in detail.

If Y is less than MSY_c, the catch of fish is judged to be less than the available fish production and, hence, more development may be accommodated on the lake. However, the wisdom of exploiting a fishery right up the MSY_c is questioned in this report, and the need to partition the MSY_c for individual species of fish is recognized. It was found, for example, that very few large, mature lake trout were showing up in the anglers' catches on lakes where the yield of native lake trout exceeded about 20% of the MSY_c. This indicates a deterioration in quality of the fishery (few trophy size fish being caught) and a possible decline in spawning stocks. Accordingly, it is recommended that the allowable harvest for lake trout be set at 20% of the MSY_c. Appropriate percentages for other species of fish have been suggested in the report of SPOF Working Group 12 (Ontario Ministry of Natural Resources 1982).

In the final section of the report, which deals with application of the model in a planning context, two options are given. The planners may determine whether a proposed number of new cottages, when added to the existing number, is likely to generate too much fishing pressure and a catch in excess of the allowable yield, or they can estimate the maximum number of cottages which could be built around the lake without causing too much angling pressure. Strictly speaking, use of the net productivity model should be confined to lakes within the designated area of Muskoka and Haliburton, and to lakes having areas, mean depths, total dissolved solids and cottage numbers within those ranges included in this study. However, the data borrowed from the literature (Table 1c), and results of additional creel censuses carried out in the summer of 1979 on Lower Buckhorn and Lovesick Lakes in the Kawartha Lakes chain and Silent and St. Peter in the Bancroft area, suggest that use of the model can be extended to regions adjacent to Muskoka and Haliburton.

Possible links between the net productivity model and other components of the Lakeshore Capacity Study are discussed in the final section of this report.

Table 1a. Morphometric and chemical characteristics, number of cottages, principal sport fish species and years of census for the Net Productivity Study lakes in the *Muskoka* area.

Name of lake	Area in ha	Mean depth in m	*TDS mgL^{-1}	**MEI	No. of cottages	LT	WF	SM	NP	SMB	LMB	WL	YP	†Years when lake censused Summer 75	76	77	78	Winter 76	77	78
Bella	337.9	16.2	33	2.04	80	X		X		X				12				14	14	
Bernard	2185.3	15.8	36	2.28	229	X		X		X			X	22	24	34	24	13	13	16
Doe	1186.9	5.9	34	5.76	175				X	X		X	X	20	21	30	24			
Eagle (Machar)	990.7	6.1	31	5.08	97			X	X	X			X	20	23					
Hodson	354.9	4.1	37	9.02	144					X		X		12	19					
Joseph	4972.8	25.3	34	1.34	1109	X		X		X				19	22	39	24	13	13	17
Kahshe	783.4	4.9	31	6.32	492					X	X		X	21						
Kawagama	2818.6	21.8	31	1.42	433	X				X				17	26	39	22	13	13	17
Lake of Bays	7052.9	22.3	32	1.43	1595	X	X	X		X				15	27	39	22	14	13	15
Muskoka	10521.8	16.8	42	2.50	4799	X	X			X			X	21	14	36		19	25	
Peninsula	864.8	9.0	47	5.22	288	X		X		X				14						
Pevensey	155.4	9.1	31	3.41	37	X	X								22			14	13	
Pickerel	513.1	8.6	35	4.07	77				X	X		X		16	21	28	23			
Rebecca	210.4	7.9	35	4.43	56	X		X		X				9					14	
Rosseau	5827.5	25.5	43	1.68	1543	X	X	X		X				18	23	42	25	14	13	17
Sand	527.2	22.2	34	1.53	191	X	X	X		X				9						
Skeleton	2155.4	28.9	35	1.21	386	X	X	X		X		X		15	27	37	25	13	13	17
Sweny	135.2	11.1	31	2.79	37	X	X								22			14	13	
Three Mile	929.2	3.5	28	8.00	356					X		X	X	20	22					
Vernon	1443.0	12.7	36	2.83	232	X		X		X				10						

*TDS = total dissolved solids
**MEI = morphoedaphic index = TDS/mean depth
†The data in the columns are the numbers of days on which the creel censuses were conducted.
X indicates the species taken by anglers.

LT = lake trout
RBT = rainbow trout
WF = whitefish
SM = smelt
NP = northern pike
ML = muskellunge
SMB = smallmouth bass
LMB = largemouth bass
WL = walleye
YP = yellow perch

Table 1b. Morphometric and chemical characteristics, number of cottages, principal sport fish species and years of census for the Net Productivity Study lakes in the *Haliburton* area.

Name of lake	Area in ha	Mean depth in m	*TDS mgL^{-1}	**MEI	No. of cottages	LT	WF	SM	NP	ML	SMB	LMB	WL	YP	†Years when lake censused Summer 75	76	77	78	Winter 76	77	78
Big Hawk	388.5	16.7	32	1.92	90	X					X	X			30	52					
Boshkung	715.9	23.1	43	1.86	281	X					X			X	30	55	45	24	57	47	33
Brady	89.4	4.5	39	8.67	58					X	X	X		X	20						
Dalrymple	1332.6	2.4	177	73.75	395				X	X	X	X	X	X	38	42	42				
Davis	94.0	10.0	78	7.80	126						X			X				21			
Drag	1002.8	18.0	50	2.78	274	X					X			X	35	54			29	49	
Esson	239.6	10.9	82	7.52	99	X					X			X	42	60	51			44	
Four Mile	742.2	8.5	136	16.00	410					X	X	X	X	X	42	57	45	23			
Glamor	194.6	8.8	70	7.95	106						X			X	35	58					
Gull	995.1	16.5	57	3.45	410	X					X			X	27	59	46	25	57	44	29
Haliburton	997.6	17.4	46	2.64	438	X					X			X	37	50	48	15			
Halls	539.8	28.3	35	1.24	237	X										8			47		
Head	918.6	3.5	107	30.57	239					X	X		X	X	29	49	43	22			
Kashagawigamog	778.4	13.0	57	4.38	491	X					X		X	X	39	30	46	25	26	45	
Kennisis	1360.1	22.9	32	1.40	510	X					X			X	36	48	50	24	30	49	28
Long	88.0	5.5	71	12.91	82						X	X		X				20			
Miskwabi	267.9	19.1	69	3.61	67	X					X	X		X	39	54	46	22	29	51	30
Mississagua	587.6	17.7	43	2.43	217	X					X			X	35	60				22	
Mountain	319.3	13.4	45	3.36	215	X					X			X				22	38		
Percy	341.0	10.8	44	4.07	16	X					X							11			
Redstone	1193.0	21.9	73	3.33	150	X					X				39	50	47		32	47	32
Twelve Mile	336.7	11.7	46	3.93	228	X					X			X	30	54	47		52	40	28

*TDS = total dissolved solids
**MEI = morphoedaphic index = TDS/mean depth
†The data in the columns are the numbers of days on which the creel censuses were conducted.
X indicates the species taken by anglers.

LT = lake trout
RBT = rainbow trout
WF = whitefish
SM = smelt
NP = northern pike
ML = muskellunge
SMB = smallmouth bass
LMB = largemouth bass
WL = walleye
YP = yellow perch

Table 1c. Morphometric and chemical characteristics, number of cottages, principal sport fish species and number of days on which creel censuses were conducted on Net Productivity Study lakes in the *Kawartha* and *Bancroft* areas during the *summer of 1979*.

Name of lake	Area in ha	Mean depth in m	*TDS mgL^{-1}	**MEI	No. of cottages	LT	RBT	WF	SM	NP	ML	SMB	LMB	WL	YP	# days census conducted in summer 1979
Silent	109	6.2	37	5.97	0	X						X	X		X	20
St. Peter	234	7.6	54	7.10	200	X	X					X	X		X	19
Lower Buckhorn	1234	3.5	116	33.14	400						X	X	X	X	X	36
Lovesick	257	2.5	119	47.60	103						X	X	X	X	X	29

*TDS = total dissolved solids
**MEI = morphoedahic index = TDS/mean depth
X indicates the species taken by anglers.

LT = lake trout
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1. INTRODUCTION

1.1 THE NET PRODUCTIVITY MODEL IN CONTEXT

Fisheries (the net productivity model) is one component of the Lakeshore Capacity Study being carried on cooperatively by the Ontario Ministries of Municipal Affairs and Housing, Environment, and Natural Resources. Construction of cottages and other facilities which attract people to a lake can affect the fisheries by: (1) changing the water chemistry and trophic status; (2) altering or disturbing spawning, nursery and feeding grounds; and (3) increasing fishing pressure. The net productivity model deals with the roles of trophic status and angling pressure in the sport fisheries, and incorporates the concepts of the morphoedaphic index and maximum sustained yield. It describes the yield of fish as a function of physical and chemical characteristics of the watershed, as well as the biotic potential of the fish and the fishing pressure.

The following constraints were placed on the model: (1) information required for the model had to be gathered within a designated and restricted geographic area; and (2) data required in order to use the model would eventually be available in existing records, or easily obtainable with a minimum of field work.

1.2 THE CONCEPT OF TROPHIC STATUS

A review of the literature on trophic status is outside the scope of this report, but a brief explanation of the concept and terminology is in order.

The adjective trophic comes from the Greek word for food. Phosphates, nitrates, lime and other chemical substances, which leach into a lake from the watershed, serve as nutrients or food for a host of microscopic plants called phytoplankton which drift about in the upper layers of lake water. These plants are food for minute animals (zooplankton and bottom fauna) which are in turn eaten by small fish. The small fish in their turn are preyed on by large game species. Hence, the production of sport fish and each intermediate link in the food chain depends ultimately on the supply of nutrients (Fig. 1). Lakes which have a poor supply, taking into account all other factors that influence productivity, are said to be oligotrophic, while those which are richly supplied are called eutrophic; the prefixes coming from the Greek for poor and rich, respectively. Lakes in an intermediate state are mesotrophic.

Lakes located in the sparse soils and granitic rocks of the Precambrian Shield tend to be oligotrophic, whereas those in deep glacial overburden and limestone bedrock are usually meso- or eutrophic. Once phosphates and other plant nutrients enter a lake, they may accumulate with the result that an oligotrophic lake could conceivably go through mesotrophic and eutrophic stages with the passage of time. Under natural conditions, this process could take thousands of years but, when man enters the picture with sewage, agricultural runoff and so forth, it can be accelerated.

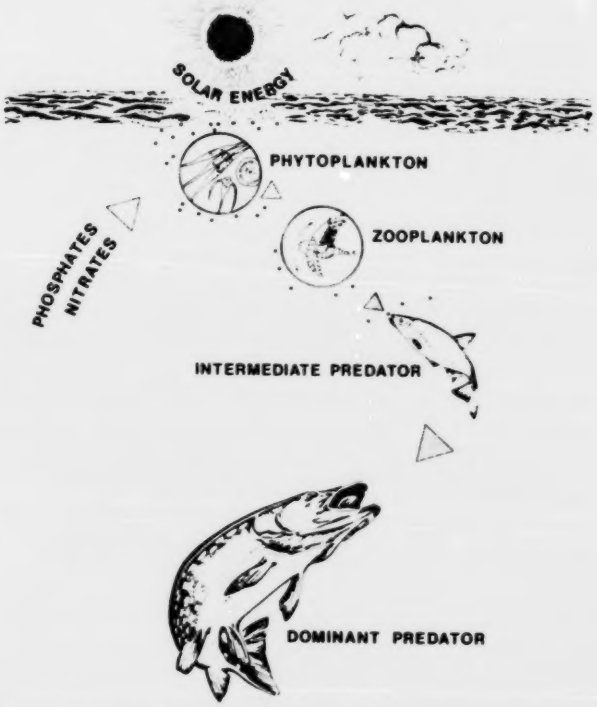

Figure 1. A typical aquatic food chain illustrating the connection between dissolved solids such as phosphates and nitrates, solar energy and, ultimately, the production of game fish (e.g. northern pike).

Because the phytoplankton require solar energy as well as nutrients to synthesize their substance, the shape of the lake basin also plays an important part in trophic status. The fraction of the lake volume receiving sufficient sunlight to support photosynthesis is usually smaller for a deep lake than for a shallow one, although dense phytoplankton populations may reduce the light penetration in shallow lakes by their shading effect. On the other hand, deep lakes may stratify strongly with respect to temperature and chemistry during the summer and, under these circumstances, nutrients may become tied up in the deep layers of water. Lakes situated on the Precambrian Shield are often very deep relative to their areas, a feature which contributes to their oligotrophy. Substances such as phosphates, nitrates, etc., which drain into the lake from the watershed, are edaphic factors; the term deriving from the Greek word for soil. The size and shape of the lake basin are, of course, morphometric factors.

Generally speaking, the trophic status of a lake can be measured either in terms of water chemistry or as production at some level in the food chain. The first category includes total dissolved solids concentrations, total alkalinities, phosphorus loadings, spring phosphorus concentrations and

dissolved oxygen deficits. The second category includes chlorophyll concentrations and standing crops of plankton or bottom fauna. The morphoedaphic index to be described in following paragraphs, combines water chemistry with lake morphometry and relates the trophic status of the lake, as measured by production of game and commercial fish, to the geology of the lake basin and watershed.

1.3 BACKGROUND AND DEVELOPMENT OF THE MORPHOEDAPHIC INDEX

Rawson (1952, 1955) was probably the first to give a clear demonstration of the relation between fish production and lake morphometry. When he plotted annual commercial fish landings, Y, against mean depths, Z, for 13 large North American lakes, he obtained the line:

$$Y = 30.255(Z)^{-0.7029} + 0.5 \qquad (1)$$

where Y was in pounds acre^{-1} and Z in feet.

On the other hand, Moyle (1956) found that commercial fish landings from Minnesota lakes were positively correlated with the total phosphorus, total nitrogen and total alkalinity of lake waters, and that these factors were in turn related to the geology of the respective watersheds. A similar relation between yields of fish, water chemistry and geology has been described by Ryder (1964a, b) for Ontario lakes.

Although the investigations by Rawson, Moyle and Ryder were based on commercial fish landings, they are nonetheless relevant to the Net Productivity Study, since most of the species taken commercially were also sport fish.

On plotting annual catches from 23 moderately to heavily fished lakes in or bordering Canada, against the ratio of total dissolved solids concentration to mean depth, Ryder (1964a, 1965, 1978) obtained the regression line:

$$Y = 1.4(TDS/Z)^{0.45} = 1.4(MEI)^{0.45} \qquad (2)$$

where Y is the yield of fish in kg ha^{-1}yr^{-1}; TDS is the total dissolved solids concentration in mg L^{-1} and Z the mean depth of the lake in m[1]. The TDS is a relatively easily determined measure of the overall contribution of nutrient elements to the lake from the watershed (the edaphic factors) and the mean depth is an indicator of the fraction of the lake volume suited to photosynthesis. Because it combined edaphic and morphometric factors in this way, Ryder termed the ratio TDS/Z, the morphoedaphic index. It will be referred to as the MEI throughout the following text of this report.

More recently, the MEI model has been fitted to data from 103 reservoirs in the United States (Jenkins and Morais 1971), 30 or more African lakes (Henderson et al 1973; Henderson and Welcomme 1974), and some lakes in northern Finland (Ryder et al 1974), indicating the universality of the concept. However, it was found that fish yields are influenced by latitude as well as MEI. The yield for a given MEI is higher for a tropical lake than for a northern one (Henderson et al 1973), owing to the greater intensity and duration of insolation on the former.

[1]The form of Ryder's equation given here was derived by converting his original data from lbs and ft to kg and m and refitting the regression line.

The reservoirs studied by Jenkins and Morais (1971) afforded a wider range of MEIs than Ryder's 23 lakes, and they found that the line relating yield to MEI took the form:

$$\log_{10} Y = 1.725\log_{10}MEI - 0.477(\log_{10}MEI)^2 + 0.0765 \qquad (3)$$

where Y was the catch of sport fish in kg ha^{-1}yr^{-1}. That is, the line is curvilinear even on a double logarithmic plot. A polynomial fit to the data for Ryder's lakes improves the correlation only slightly ($r = 0.8652$, compared with $r = 0.8556$ for the linear fit), but it probably gives a better prediction of yields towards the upper end of the MEI range. It takes the form:

$$\log_{10}Y = 0.620(\log_{10}MEI) - 0.118(\log_{10}MEI)^2 + 0.115 \qquad (4)$$

Jenkins and Morais (1971) and Henderson and Welcomme (1974) found that catches of fish were also strongly correlated with the fishing pressure and the latter team combined yield (catch), MEI and commercial fishing effort in a single model. They used the number of fishermen involved in each fishery as the measure of effort, on the assumption that all their fishermen were equally efficient. In examining the relation between yield, MEI and commercial fishing effort for percid communities in certain Ontario lakes, Adams and Olver (1977) considered differences in the ratio $Y/\hat{Y}$, which they termed the "relative yield intensity", to be due in large measure to lake-to-lake differences in fishing pressure. Here Y is the observed yield to the fishermen, and $\hat{Y}$ the value computed from Ryder's MEI formula.

Other investigators have dealt with the intermediate links in the food chain. For example, Oglesby (1977) demonstrated strong correlations between fish yields and summer standing crops of phytoplankton, and between fish yields and phytoplankton productivity. Matuszek (1978) reported that fish yields were strongly correlated with the dry weight of standing crops of bottom fauna in 19 large lakes and 3 large lake basins in North America. The relation between standing crops of phytoplankton, measured as chlorophyll-*a* concentrations, and the MEIs for those Net Productivity Study lakes, for which the data are available, is shown in Fig. 2.

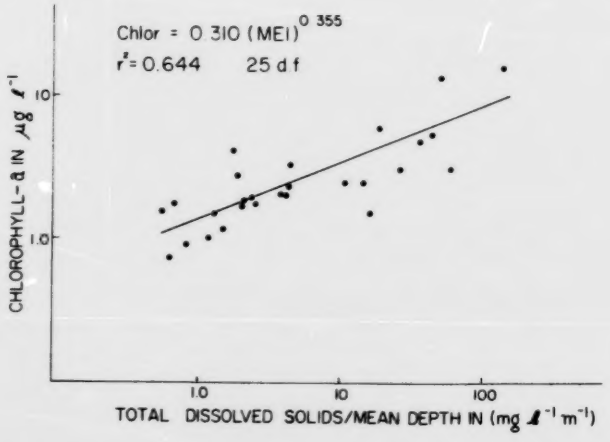

Figure 2. The relation between primary productivity, as measured by chlorophyll-*a* concentration, and the MEI for Net Productivity Study lakes censused in 1977 and 1978. Here, $r = 0.803$ with 25 d.f. and the equation for the regression line is Chlor = $0.310(MEI)^{0.355}$

In selecting the 23 lakes for the MEI model, Ryder assumed that since the fisheries had been carried on over many years, the catches indicated the continuing availablity of fish. However, following the period from which Ryder drew his data, the fisheries in several of the lakes (notably the Laurentian Great Lakes and Great Slave Lake) deteriorated. According to reviews by Smith, Keleher, Lawrie and Rahrer, Berst and Spangler, Hartman, Christie, and Wells and McLain in the SCOL Symposium (1972), heavy and increasing fishing pressure was a major factor, although pollution and lamprey predation also played a role in the decline of the Great Lakes fisheries. Accordingly, the yield estimated from the MEI model has been used as one of the criteria for setting quotas for some Ontario fisheries. For example, commercial fish landings for Lake of the Woods were restricted recently when it was found that previous catches of commercial and sport fish combined exceeded the value obtained from the MEI formula. In contrast, Lewies (1976) reported that sport fish catches from the Kawartha lakes fell considerably short of the Ryder estimate, suggesting that these waters might be underexploited.

In the formulation of the net productivity model, the yield obtained from Ryder's MEI model has been taken as an estimate of the maximum sustainable yield for a fish community, MSY_c. However, a somewhat better estimate might be obtained from the MEI model derived by Matuszek (1978), since he made certain that the yield data used in his model were averages for extended periods of overall peak yields from intensively fished commercial fisheries. He also suggests that somewhat different models might be appropriate for different fish communities.

1.4 FORMULATION OF THE NET PRODUCTIVITY MODEL

The net productivity model developed in this report is an extension of the MEI model and is described by the equation:

$$P_n = Y/MSY_c \qquad (5)$$

where P_n is the net productivity index, Y the weight of fish removed by anglers (referred to as the angling yield), and MSY_c is the estimated maximum sustainable yield; all stated in kg $ha^{-1}yr^{-1}$ or kg $ha^{-1}season^{-1}$. Creel censuses conducted in the present study indicate that the fraction of the catch, which the anglers release, is small enough to be neglected in this model.

Here, the MSY_c is the particular value of Y obtained by inserting the MEI for the lake in question into Ryder's MEI formula (Equation 2). The subscript denotes that the value obtained from that formula is the maximum sustainable yield for a fish community subjected to conventional techniques and preferences, rather than the maximum sustainable yield for an individual species. The relation between the MSY for a species and the MSY_c will be dealt with in a later section.

The Y in Equation (5) is derived stepwise from a series of regressions based on data collected in creel censuses on 46 lakes in the Muskoka and Haliburton regions of central Ontario during 1975-79 plus additional data for 10 lake basins selected from the literature. In the order in which they are used, these regressions are: (1) summer angling effort per cottage by cottagers on area of lake; (2) summer effort by noncottagers on summer effort by cottagers; (3) total winter effort by all anglers on total summer effort by cottagers and noncottagers combined; and (4) total summer yield on MEI and total summer effort by cottagers and noncottagers.

If Y is greater than MSY_c, this fishery is considered to be endangered, whereas if Y is less than MSY_c, it is assumed that there are fish to spare and more fishing pressure could be allowed. However, the wisdom of exploiting a fishery up to the MSY_c is questioned in later sections of this report, and appropriate modifications to this component of the model are suggested. Rationales for partitioning the MSY_c for individual species will also be considered.

The MEI referred to here is based on the current dissolved solids concentration. The extent to which this concentration may be augmented by phosphorus, nitrogen and other elements from sewage systems of projected cottage development is not clear at present. However, the possibility of such a "feedback" mechanism will be discussed in the conclusions.

In the following text, the term cottager applies to anyone who owns, rents or visits a cottage at the lake, while a noncottager is one who has access to the lake through a lodge, hotel, campsite park, marina or launching site. Any angler with a permanent residence of a lake is regarded here as a cottage angler, as is any angler coming from a cottage which lies within the immediate watershed of the lake, but does not have water frontage. On the other hand, an angler coming from a cottage on another lake is included amongst the noncottagers.

2. METHODS

2.1 SELECTION OF THE STUDY LAKES

Roving creel censuses were conducted on 46 lakes in the Haliburton and Muskoka regions of Ontario during the summer and winter angling seasons of 1975-1979 (Table 1a, b, c). The lakes were selected to give a representative sample of areas, depths, total dissolved solids concentrations, numbers of cottages and fish species while, at the same time, minimizing travel time between lakes. Since all of these lakes lie within 44°-46° north latitude, differences in insolation are considered to be negligible. According to Ryder (1965), an MEI of about 6.6 mg $L^{-1}m^{-1}$ appears to separate eutrophic from oligotrophic lakes. Most of the lakes in the Net Productivity Study are located on the Precambrian Shield and have MEIs less than 6.6. However, Head, Four Mile, and Dalrymple Lakes lie mostly within limestone plains and have MEIs greater than 6.6.

2.2 CREEL CENSUS PROCEDURES

Owing to the large number of creel census takers involved, and the logistics of getting to the lakes, a purposive (Regier 1966) rather than a randomized sampling schedule was adopted. Tables 1a, b, and c show which lakes were censused each year and how many census days were spent on each. The census takers were divided into crews of 3 or 4 people, each assigned to a group of lakes. Generally, the census was conducted on a different day of the week each time, on a rotating schedule. However, care was taken to include an adequate sample for each lake of the angling on weekends and statutory holidays. The census takers visited the lakes on each scheduled day, regardless of weather and number of anglers.

A census taker made at least one trip around the lake on each census day, interviewing all anglers on the census route. Each party was interviewed only once per day. The number of anglers in the party, the hours fished up to time of interview, the total hours which the anglers estimated they would fish that day, the type and origin of the anglers, and the number of fish caught, released and sampled were recorded. If no fish were caught, zeros were entered into the appropriate spaces on the record form. Effort statistics given in this report include both successful and unsuccessful angler-hours. When possible, fish length and weight data were also taken. Information such as the time spent interviewing anglers on the lake, was entered into a diary.

2.2.1 ASSUMPTIONS MADE IN PRORATING THE CREEL CENSUS DATA

In prorating the data recorded in the creel census, to obtain catch and effort statistics for an entire angling season, it was assumed that an angler's chances of catching fish following the interview were as good as before the interview. Support for this assumption is found in the investigations of Grosslein (1962), Malvestuto et al (1978), and Fierstine et al (1978).

Since angling seasons for various species do not always coincide with respect to opening and closing dates, and because seasons may vary from year to year, it was necessary to assign an arbitrary number of days, d', to each season. For the summer season, d' was taken to be 153 days (May 1 to September 30) and for the winter, it was considered to be 91 days (January 1 to March 31). The average length of an angling day, t', was taken as 12 hours for summer and 8 hours for winter. These times represent the average number of daylight hours for the respective seasons, minus 1 hour in the morning and 1 hour in the evening to allow anglers to travel to and from fishing sites in daylight.

2.2.2 FORMULAE USED IN PRORATING THE CREEL CENSUS DATA

The formula used to calculate the summer or winter angling yield, Y_{cc}, in kg ha^{-1} $season^{-1}$ is:

$$Y_{cc} = ((C - R)(t'/t)(d'/d)(h'/h)(W))/A \qquad (6)$$

where C and R are the total numbers of fish caught and released respectively during the season, as tallied in the creel census; t' is the total possible hours of fishing per day, averaged over the season; t is the seasonal average hours per day which the census taker spent interviewing anglers; d', the total number of days in the angling season; d, the total number of census days per season; h'/h, the seasonal total of the number of hours that the anglers estimated they would fish per day, divided by the seasonal total of the hours up to time of interview; W, the average weight of a fish, based on the samples; and A, the area of the lake. All parameters except t' and d', which are evaluated in the paragraph above, are calculated for the individual lakes. Since almost all of the fish caught and kept by the anglers were sampled, W is a good estimate of the average weight of a fish removed from the lake.

The formula for calculating E_{cc}, the angler-hours ha^{-1} $season^{-1}$ of effort on the lake is:

$$E_{cc} = ((E')(t'/t)(d'/d)(h'/h))/A \qquad (7)$$

where E' is the product of the number of anglers per party times the hours fished up to the interview summed over the season, and t'/t, d'/d, and h'/h are as defined in the preceding paragraph.

Where there is only a summer fishery, the kg ha^{-1} $season^{-1}$ and angler-hours ha^{-1} $season^{-1}$ are equivalent to the kg ha^{-1} yr^{-1} and angler-hours ha^{-1} yr^{-1}, respectively. Where both summer and winter angling occurs, the yields and efforts per hectare are calculated separately for each season and then added to get the yearly values.

2.3 RECORDS OF PLANTED LAKE TROUT

Lake trout planted in Ontario waters are generally marked by removal of the adipose fin, an appendage which shows little or no tendency to regenerate. They may also have one of the pectoral or pelvic fins clipped to indicate the year of planting. Consistant records of all marked lake trout in catches from the study lakes were kept during the summers of 1977-1978 and winters of 1978-1979. Samples of scales for age determination were also taken from almost all fish sampled in those years.

2.4 SOURCES OF MEI AND COTTAGE DEVELOPMENT INFORMATION

Areas, mean depths, and total dissolved solids concentrations for the Net Productivity Study lakes were obtained from records of lake surveys in the respective MNR District Offices and from the Environmental Dynamics Section, Fisheries Branch, MNR. Because total dissolved solids concentrations vary with the season, Ryder (1964a) recommended that for consistency the midsummmer minimum be used in calculating the MEI. In practice, this amounts to using the lowest value recorded for July and August. The numbers of cottages on the lakes were taken from records of land use surveys in the District Offices with help from the Land Use Coordination Branch, MNR.

2.5 CREEL CENSUS DATA FROM THE LITERATURE AND 1979 NPS CENSUSES

The averages of the angling effort and yield data obtained in the Net Productivity Study (NPS) creel censuses during the years 1975-78 on the Haliburton and Muskoka area lakes are given in Table 2a and 2b respectively.

Table 2c lists additional yield, effort and MEI data extracted from the literature (Armstrong 1966; Bernier 1977, 1978; Lewis 1978; Olver 1968, 1971, 1972; Schupp 1978), or gathered during the 1979 Net Productivity Study creel censuses for 14 lakes or lake basins lying outside the Muskoka and Haliburton regions. These data were included in the regressions of yield on MEI, yield on effort, and yield on MEI and effort combined (to be described in following sections) for two purposes. First, they permit a comparison between the data collected in the net productivity creel censuses with those collected on individual lakes by more intensive and/or more rigorously designed creel censuses. Secondly, they provide additional yield data for lakes at the upper end of the MEI range.

However, the data from these 14 lakes have not been used in deriving the regression lines relating cottager effort per cottage to lake area, and cottager effort to noncottager effort, because information on the number of cottages was not on hand at the time of analyses. The data could not be used to relate winter angling to summer angling, since there is little or no winter angling on these lakes.

Table 2a. Values for MEI, MSY_c, average angling efforts, yield of fish (all species combined), and yield/MSY_c ratios for the Net Productivity Study lakes, in the *Haliburton* area, *for 1975-1978*.

			Effort in angler-hours ha^{-1}			Yield in kg ha^{-1}			Yield/MSY_c	
			Summer season		Winter	Summer season		Winter	All anglers	
*Name of Lake	MEI $mg\ L^{-1}m^{-1}$	**MSY_c $kg\ ha^{-1}yr^{-1}$	Cottagers	All anglers	All anglers	Cottagers	All anglers	All anglers	For summer	For year
Haliburton lakes										
Halls	1.24	1.54	8.35	14.60	19.9	0.09	0.19	0.52	0.12	0.46
Kennisis	1.40	1.63	7.18	9.87	15.6	0.70	1.01	1.31	0.62	1.42
Boshkung	1.86	1.85	5.46	8.79	51.0	0.41	0.56	2.09	0.30	1.43
Big Hawk	1.92	1.88	13.71	24.40		1.05	1.92		1.02	1.02
Mississagua	2.43	2.09	11.68	14.50	3.6	0.62	0.74	0.19	0.35	0.45
Haliburton	2.64	2.17	6.42	7.86		0.54	0.62		0.29	0.29
Drag	2.78	2.22	3.84	9.88	4.7	0.14	0.52	0.16	0.23	0.31
Redstone	3.33	2.40	5.99	12.10	10.8	0.32	0.77	0.77	0.32	0.64
Mountain	3.36	2.41	10.32	15.80	33.3	0.57	0.61	1.13	0.25	0.72
Gull	3.45	2.44	3.60	6.36	30.0	0.22	0.11	1.85	0.05	0.80
Miskwabi	3.61	2.49	14.90	44.40	39.6	3.26	7.21	4.24	2.90	4.60
Twelve Mile	3.93	2.59	11.47	15.40	45.8	1.27	1.52	1.74	0.59	1.26
Percy	4.07	2.63	7.70	42.40		0.00	4.70		1.79	1.79
Kashagawigamog	4.38	2.72	4.64	16.40	3.9	0.36	1.30	0.22	0.48	0.56
Esson	7.52	3.47	30.74	47.00	28.5	2.72	4.60	1.34	1.32	1.71
Davis	7.80	3.53	27.53	31.00		1.73	2.45		0.69	0.69
Glamor	7.95	3.56	20.21	31.20		2.64	3.88		1.09	1.09
Brady	8.67	3.70	27.18	31.00		1.05	2.77		0.75	0.75
Long	12.91	4.43	36.48	84.30		6.82	9.06		2.04	2.04
Four Mile	16.00	4.87	12.94	14.28		1.70	1.91		0.39	0.39
Head	30.57	6.52	10.98	18.70		1.61	3.15		0.48	0.48
Dalrymple	73.75	9.70	11.40	33.80		1.13	2.41		0.25	0.25

*Arranged in ascending order of MEI

**$MSY_c = 1.4(MEI)^{0.45}$

Table 2b. Values for MEI, MSY_c, average angling efforts, yield of fish (all species combined), and yield/MSY_c ratios for the Net Productivity Study lakes, in the *Muskoka* area, *for 1975-1978*.

			Effort in angler-hours ha^{-1}			Yield in kg ha^{-1}			Yield/MSY_c	
			Summer season		Winter	Summer season		Winter	All anglers	
*Name of Lake	MEI mg $L^{-1}m^{-1}$	**MSY_c kg $ha^{-1}yr^{-1}$	Cottagers	All anglers	All anglers	Cottagers	All anglers	All anglers	For summer	For year
Muskoka lakes										
Skeleton	1.21	1.52	3.29	6.04	6.48	0.29	0.53	0.81	0.35	0.88
Joseph	1.34	1.60	1.35	2.68	2.27	0.20	0.36	0.48	0.23	0.53
Kawagama	1.42	1.64	3.60	5.34	1.90	0.36	0.52	0.35	0.32	0.53
Lake of Bays	1.43	1.64	0.94	1.35	0.96	0.09	0.10	0.11	0.06	0.13
Sand	1.53	1.69	4.68	11.60		0.31	0.98		0.58	0.58
Rousseau	1.68	1.77	0.87	1.55	0.51	0.10	0.19	0.26	0.11	0.25
Bella	2.04	1.92	10.28	45.86	3.62	0.48	2.13	0.55	1.11	1.40
Bernard	2.28	2.03	1.71	4.55	3.03	0.34	0.79	0.44	0.39	0.61
Muskoka	2.50	2.11	0.55	0.88	0.26	0.07	0.12	0.04	0.06	0.08
Sweny	2.79	2.22	14.24	38.40	28.60	0.49	1.19	1.49	0.54	1.21
Vernon	2.83	2.23	6.18	16.44		0.12	0.53		0.24	0.24
Pevensey	3.41	2.43	19.54	32.36	11.30	0.86	1.33	0.34	0.55	0.69
Pickerel	4.07	2.63	14.74	35.87		1.00	2.59		0.98	0.98
Rebecca	4.43	2.73	16.19	49.00		0.16	2.45		0.90	0.90
Eagle (Machar)	5.08	2.91	5.76	17.87		0.42	1.41		0.48	0.48
Peninsula	5.22	2.94	4.[illegible]	11.76		0.98	1.48		0.50	0.50
Doe	5.76	3.08	11.30	38.49		1.15	3.37		1.09	1.09
Kahshe	6.32	3.21	8.10	15.14		1.64	2.14		0.67	0.67
Three Mile	8.00	3.57	13.61	32.58		1.32	3.21		0.90	0.90
Hodson	9.02	3.77	27.70	47.52		4.48	8.50		2.25	2.25

*Arranged in ascending order of MEI

**Calculated from Ryder's equation: $MSY_c = 1.4(MEI)^{0.45}$

Table 2c. Values for MEI, MSY_c, average angling efforts, yield of fish (all species combined), and yield/MSY_c ratios for lakes described in the literature and for the Net Productivity Study lakes creel censused in *summer of 1979*.

			Effort in angler-hours ha^{-1}			Yield in kg ha^{-1}			Yield/MSY_c	
			Summer season		Winter	Summer season		Winter	All anglers	
*Name of Lake	MEI mg $L^{-1}m^{-1}$	**MSY_c kg $ha^{-1}yr^{-1}$	Cottagers	All anglers	All anglers	Cottagers	All anglers	All anglers	For summer	For year
				From the literature						
Flack	0.59	1.10		3.02			1.24		1.13	1.13
Chiblow-Denman	1.00	1.40		2.88			0.92		0.66	0.66
Semiwite	2.04	1.93		4.91			0.76		0.39	0.39
Bone	2.59	2.15		0.00	31.38		0.00	1.97	0.00	0.92
Balsam	16.2	4.90		37.20			5.60		1.14	1.14
Sturgeon	54.87	8.49		54.80			5.56		0.65	0.65
Leech Lake (Minn.)										
Walker Bay	16.4	4.93		29.15			3.79		0.77	0.77
Whipholt Bay	30.5	6.52		6.81			1.77		0.27	0.27
Pelican Island	32.8	6.73		19.44			4.86		0.72	0.72
Steamboat Bay	81.7	10.15		25.39			8.38		0.83	0.83
				Additional (1979) LCS lakes						
Silent†	5.97	3.13		62.27			5.84		1.87	1.87
St. Peter†	7.10	3.38		62.89			2.64		0.78	0.78
Lower Buckhorn°	33.14	6.76		61.81			5.04		0.75	0.75
Lovesick°	47.60	7.96		147.31			8.61		1.08	1.08

*Arranged in ascending order of MEI

**Calculated from Ryder's equation: $MSY_c = 1.4(MEI)^{0.45}$

†In Bancroft area.

°Kawartha Lakes.

3. RESULTS

3.1 SOME CHARACTERISTICS OF ANGLERS

While the mathematical models developed in the Net Productivity Study deal with the impact of an average angler on the fisheries, it is important to remember that some anglers will have more effect than others, depending on their skill, enthusiasm and familiarity with the body of water being fished.

To find out what proportion of the anglers fished the lake repeatedly and what proportion fished it only occasionally, the following questions were incorporated into the 1977 and 1978 censuses: "Have you been interviewed on this lake before, during this season?", and "If so, how many times?". In the 1978 winter creel census the total number of interviews of parties comprised of cottagers and/or noncottagers was 1390 for the Haliburton lakes and 653 for the Muskoka area lakes. Of the parties interviewed on the Haliburton lakes 728 were encountered once, 222 were interviewed twice and 133 three times, etc. (Fig. 3). On the Muskoka lakes 307 parties were interviewed once, 135 twice and 87 three times, etc.

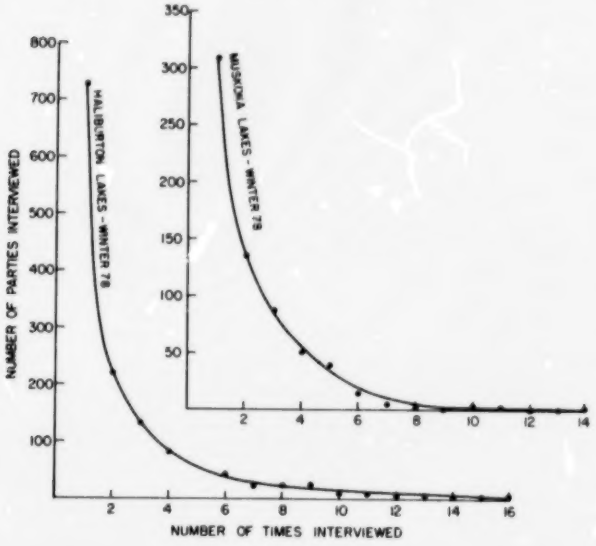

Figure 3. Frequency distribution for parties interviewed 1, 2, 3, or more times during the 1978 winter creel census. Data for all lakes in a district were pooled and lines fitted by least squares.

If the frequencies with which parties were interviewed 2, 3, 4 or more times are expressed as percentages of the number of times they were interviewed once only (Fig. 4), then the frequency distribution curves for cottagers, for cottagers and noncottagers combined, and for the summer and winter seasons are very similar. However, the curve for the Muskoka winter fishery indicates that there was a somewhat higher proportion of repeat interviews on that lake.

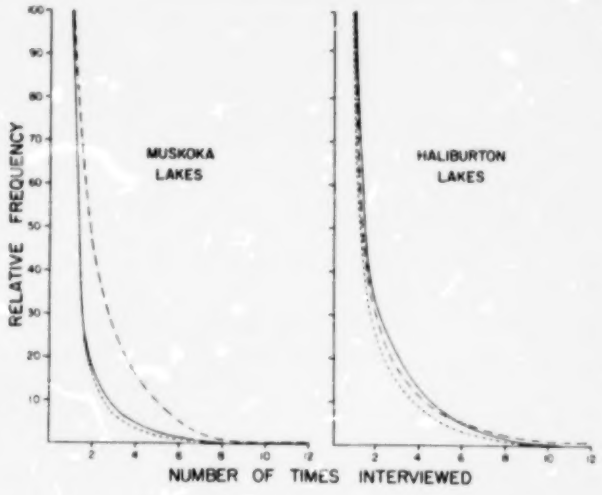

Figure 4. Relative frequency distributions of parties interviewed 1, 2, 3 or more times during the 1977 and 1978 summer and winter creel censuses. The solid line is for cottagers interviewed in the summer of 1977, the dashed line is for cottagers and noncottagers interviewed in the summer of 1977, and the interrupted line is for all anglers interviewed during the winter of 1978.

3.1.1 RELIABILITY OF REPORTED HOURS OF ANGLING

If the anglers were reasonably accurate in reporting the hours of angling up to time of interview (h), and in estimating their total hours of angling for the day (h'), one might expect to find a consistent relation between h and h'. That this is actually the case can be seen in Fig. 5, which gives typical examples for Muskoka and Haliburton lakes. Notice that the ratio h'/h decreases as h increases, because the longer the party has been fishing up to the interview, the fewer daylight hours will be left in which to fish. Notice too, that the total estimated hours for a winter day was higher for the Haliburton than the Muskoka lake.

3.1.2 HOURS OF ANGLING PER TRIP

Frequency distributions for parties angling 1, 2, 3, or more hours per day are shown in Fig. 6. The solid lines represent the hours up to time of interview, while the dotted lines show the estimated total hours per trip. In summer, most parties spent between 2 and 4 hours per day angling whereas in winter, a considerable proportion spent up to 6 hours per day. A few anglers even estimated that they would spend from 8 to 10 hours per trip in the winter.

The shorter fishing time for summer trips is probably due to the greater choice of aquatic recreational activities available to summer parties, and to the fact that such parties often include

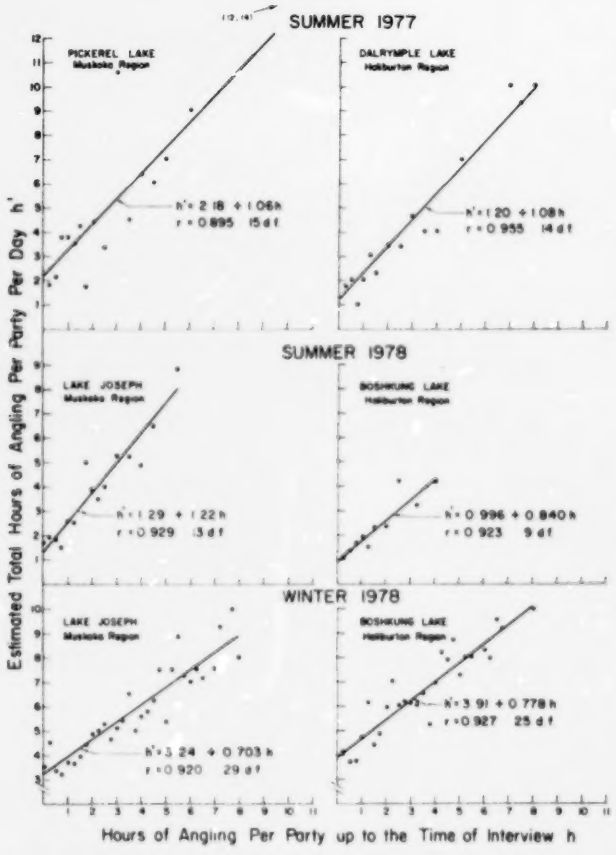

Figure 5. Typical examples of the relation between hours of angling up to time of interview and estimated total hours for the day. The lines were fitted by least squares and the respective coefficients of correlation are highly significant.

children, whose attention span for angling is short. The longer time per winter trip may reflect the difficulty in getting to the fishing site, the relative comfort of the fishing hut once one has arrived, and the amount of free time available to local residents in winter.

3.2 YIELD OF FISH AND THE MEI

Fig. 7 shows the relation between yield (Y) of fish taken during the summer by cottagers and noncottagers combined and the MEI. The data plotted are listed in Table 1a, b and c. The equation for the solid line, which was fitted by least squares is:

$$\log_{10} Y = 1.14(\log_{10}MEI) - 0.275(\log_{10}MEI)^2 - 0.406 \quad (8)$$

where Y is in kg ha^{-1} $summer^{-1}$ and the MEI is in mg $L^{-1}m^{-1}$. The correlation coefficient, r, is 0.685 with 54 d.f. and is significant at $P = 0.01$. This curve is similar to that found by Jenkins and Morais (1971) in their study of United States reservoir fisheries, except that yields for the Net Productivity Study lakes were about 1/6 of theirs. This was probably due to their waters receiving more insolation on the one hand and more fishing pressure on the other.

Differences in latitude and insolation between Leech Lake, the Sault Ste. Marie District lakes, the Kawartha lakes and the Net Productivity Study lakes, are not taken into account in the present net productivity model. A recent study by Schlesinger and Regier (1982) on 43 globally distributed and intensively exploited commercial fisheries produced the regression line:

$$\log_{10}MSY_c = 0.050(TEMP) + 0.280(\log_{10}MEI) + 0.236 \quad (9)$$

where TEMP is the mean annual temperature, in degrees Celsius, in the vicinity of the lake being fished. The r^2 values

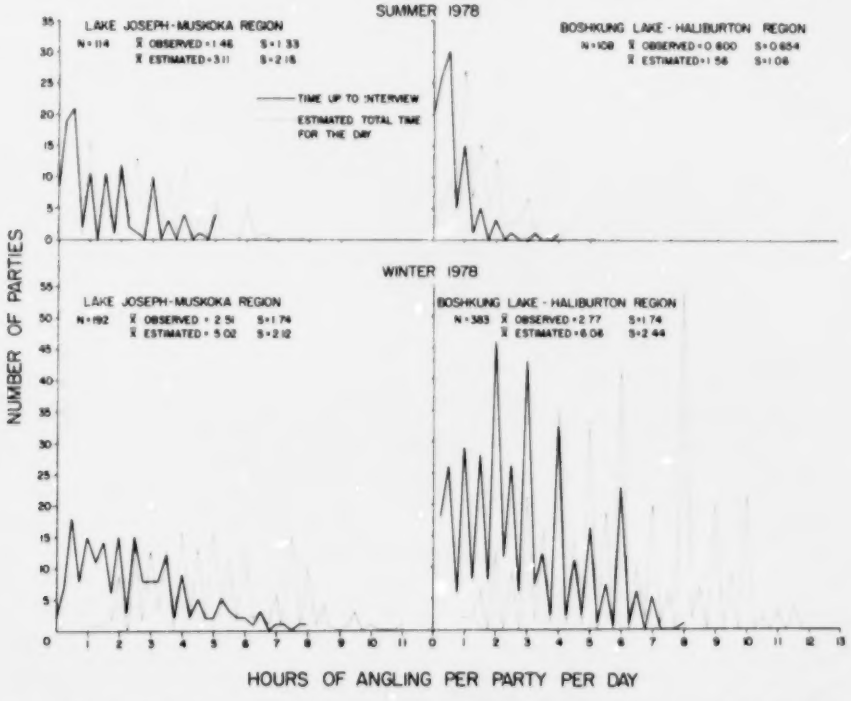
SUMMER 1978
LAKE JOSEPH-MUSKOKA REGION
BOSHKUNG LAKE - HALIBURTON REGION
TIME UP TO INTERVIEW
ESTIMATED TOTAL TIME FOR THE DAY
WINTER 1978
LAKE JOSEPH-MUSKOKA REGION
BOSHKUNG LAKE - HALIBURTON REGION
NUMBER OF PARTIES
HOURS OF ANGLING PER PARTY PER DAY

Figure 6. Typical frequency distributions of parties fishing 1, 2, 3 or more hours. The solid lines represent hours fished up to the time of interview, while the dotted lines are for estimated total hours fished per day.

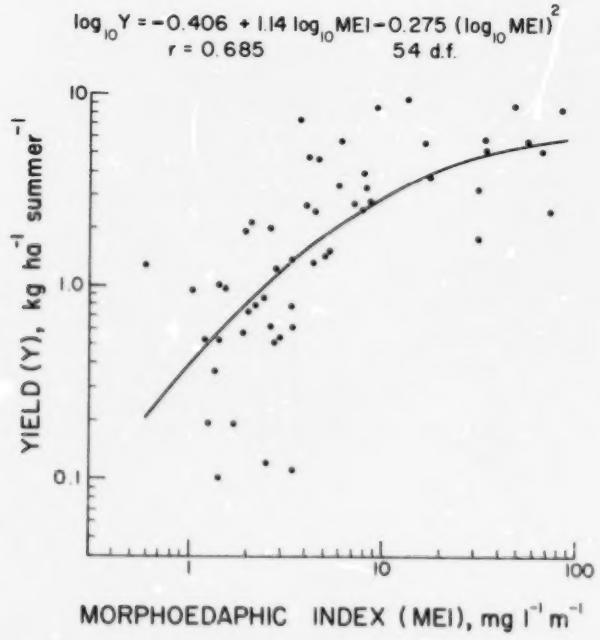

Figure 7. Relation between the summer yields of all species of fish for cottagers and noncottagers combined and the MEI (total dissolved solids/mean depth). The data plotted are given in Table 2a, b and c.

indicate that TEMP and MEI account for 74% and 7% of the variability in MSY_c, respectively. According to this relation, a lake with an MEI of 5 in the vicinity of Sault Ste. Marie (TEMP *cca* 3.8°C), would have an MSY_c of 4.18 kg ha^{-1} yr^{-1}, whereas a lake with the same MEI in the Kawartha chain near Lindsay (TEMP *cca* 6.1°C) would have an MSY_c of 5.45 kg ha^{-1} yr^{-1}. However, analyses by Schlesinger (1982) of data from the Net Productivity Study and from the SPOF Working Group 12 Report (Ontario Ministry of Natural Resources 1982) indicate that the effect of TEMP on yield cannot be distinguished on a provincial scale.

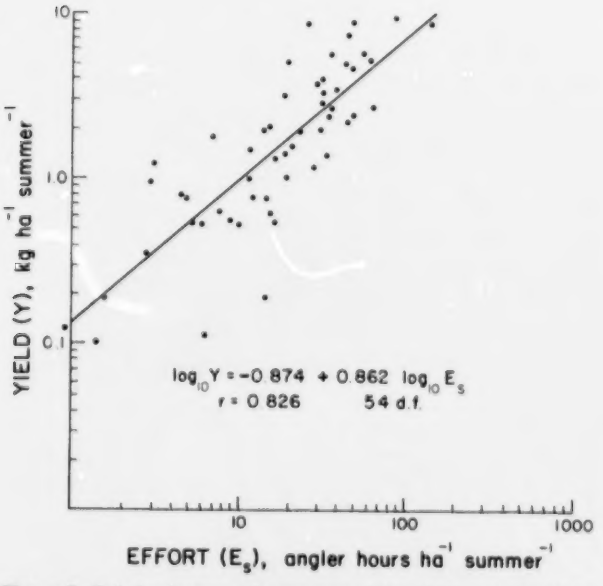

Figure 8. Relation between the summer yields of all species of fish for cottagers and noncottagers combined and the combined summer effort by cottagers and noncottagers (Table 2a, b and c).

3.2.1 ANGLING YIELDS AND ANGLING EFFORT

The angling effort and yield statistics obtained from the 1975-1978 creel censuses are summarized in Tables 2a and b, while Fig. 8 shows the relation between the summer yield of all species taken by cottagers and noncottagers combined, and the summer effort by all anglers. The solid line in the figure was fitted by least squares and takes the form:

$$\log_{10}Y = 0.862(\log_{10}E_s) - 0.874$$

or

$$Y = 0.134(E_s)^{0.862} \qquad (10)$$

where Y is the total summer angling yield in kg ha^{-1} and E_s the total summer effort in angler-hours ha^{-1} by cottagers and noncottagers combined. The r = 0.826 with 54 d.f. and is significant at P = 0.01. Here again, the picture is similar to that obtained by Jenkins and Morais (1971), except that the angling pressure on their reservoirs tended to be much higher than that on the net productivity lakes.

3.2.2 ANGLING YIELDS VERSUS THE MEI AND EFFORT COMBINED

A multiple regression of summer yield by all anglers on the MEI, and the summer effort by all anglers gave the line:

$$\log_{10}Y = 0.458(\log_{10}MEI) + 0.126(\log_{10}MEI)^2 + 0.728(\log_{10}E_s) - 0.834 \qquad (11)$$

where Y and E_s are defined in the preceding paragraph. The combination of MEI and effort markedly strengthened the correlation (r = 0.863, 54 d.f. $P < 0.01$). The properties of this function are best seen when it is plotted on arithmetic scales (Fig. 9a and 9b).

Each solid line in Fig. 9a represents angling yields for various combinations of MEI, and a specific level of angling effort. The dashed line represents the community maximum sustainable yield, MSY_c, for successive MEI values calculated from Ryder's model as stated in Equation (2). If one compares points on the solid and dashed lines at successive MEIs, the angling yield approaches the MSY_c in lakes of MEI less than 5.0, when the effort approaches 30 angler-hours ha^{-1}. Presumably, this would be the case whether the 30 angler-hours ha^{-1} was expended on a summer fishery only, or on a combined summer and winter fishery. When the effort reaches 70 angler-hours ha^{-1}, the angling yields surpass the MSY_c at all MEI values found in our study lakes.

Note that the shape of the curves relating yields to MEI shown here depends on the characteristics of the lakes sampled, and is, therefore, an approximation. The exact shape would be difficult, if not impossible, to determine. In theory, they must arise from the 0,0 origin, but it is difficult to conceive of lakes with MEI values approaching zero, that is, having infinitely small TDS or infinitely great depth. On the other hand, it is unlikely that the species of fish dealt with in this report would prosper in lakes having TDS concentrations approaching those of Great Salt Lake, Utah. Nor would they do well in extremely shallow waters. Consequently, the curves in Fig. 9a should theoretically bend downwards at MEI values higher than those represented in our sample.

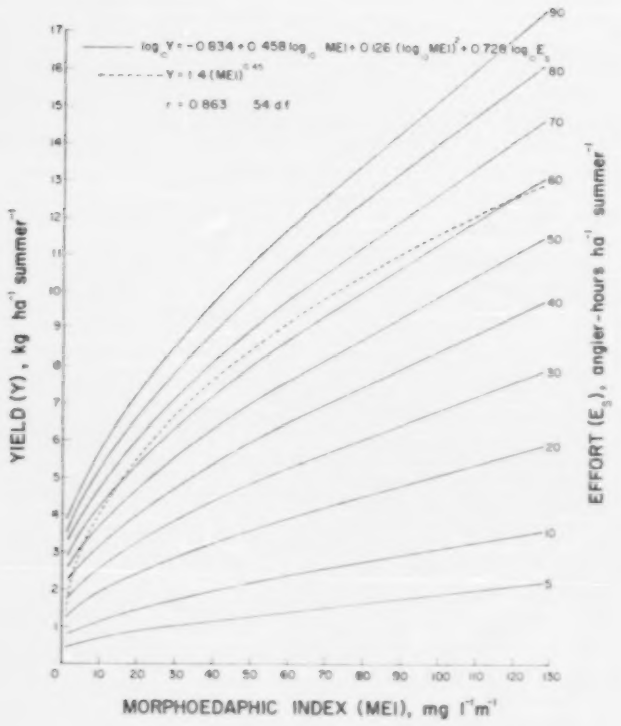
log10Y = -0.834 + 0.458 log10 MEI + 0.126 (log10 MEI)2 + 0.728 log10 Es
Y = 1.4 (MEI)1.45
r = 0.863 54 df
YIELD (Y), kg ha-1 summer-1
EFFORT (Es), angler-hours ha-1 summer-1
MORPHOEDAPHIC INDEX (MEI), mg l-1m-1

Figure 9a. Relation between summer yields of all species combined to all anglers and the MEI, at increasing levels of summer effort. Data for the solid lines were calculated form Equation (11). The interrupted line represents MSY_c values calculated for successive MEI values from Ryder's formula (Equation (2)).

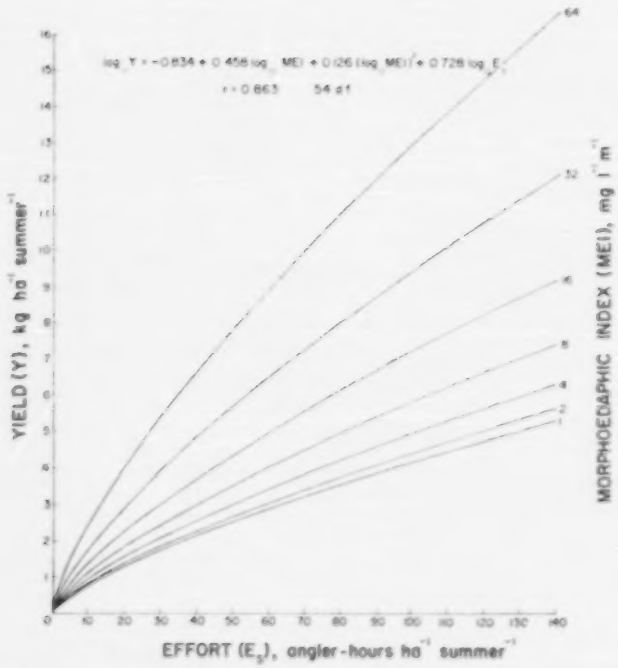
log10Y = -0.834 + 0.458 log10 MEI + 0.126 (log10 MEI)2 + 0.728 log10 Es
r = 0.863 54 df
YIELD (Y), kg ha-1 summer-1
MORPHOEDAPHIC INDEX (MEI), mg l-1 m-1
EFFORT (Es), angler-hours ha-1 summer-1

Figure 9b. Relation between summer yields of all species combined to all anglers and summer effort by all anglers, at increasing levels of MEI. Data for plotting were calculated from Equation (11), as in Figure 9a.

In Fig. 9b, the yields generated from Equation (11) have been plotted in such a way as to emphasize the relation between yield and effort at different levels of MEI. The point to be noted is that, in this case, the curves appear to rise from the 0,0 origin indicating that there can be no yield where there is no effort, as one would expect.

In 13 of the 56 fisheries used here in deriving Equation (11) and Fig. 9a and 9b, total summer angling yields exceeded the MSY_c, and in 9 of these cases, the excess was greater than 10%. The MEI values for these lakes ranged from 0.59 to 16.2 and the total summer effort by cottagers and noncottagers combined ranged from 3 to 147 angler-hours ha^{-1} (Table 2a, b and c). On the other hand, although the summer angling yields for Boshkung, Kennisis, Twelve Mile and Sweny Lakes were much less than the MSY_c, heavy winter angling raised the total annual yield 10% or more above the MSY_c.

3.2.3 COTTAGER EFFORT, NUMBER OF COTTAGES AND LAKE AREA

If some fraction of the cottager population is attracted to the lake by its angling potential, and if this fraction is more or less constant from lake to lake, one would expect to find a relation between angler-hours of cottager effort and the number of cottages. At the same time, there is evidence that effort by anglers, in general, is correlated with the size of the lake. Jenkins and Morais (1971) reported that both harvest and effort per unit area were negatively correlated with the reservoir area, the relation for the latter being:

$$\log_{10}E = 0.792(\log_{10}A) - 0.167(\log_{10}A)^2 + 1.521 \quad (12)$$

where E is the angler-hours ha^{-1} yr^{-1}, and A is the surface of the lake in ha. Carlander (1977) also found a negative correlation between the kg ha^{-1} yr^{-1} of walleye caught by anglers and the lake area. He suggested that this might be due to a decrease in angler effort per hectare as distance from shore increases. Alternatively, it may be due to the negative correlation between area of lake and area of littoral zone, since the walleye is a littoral species.

In the present case, a routine multiple regression of cottager effort on the number of cottages and area of lake was unsatisfactory, owing to the strong correlation between the number of cottages and lake area: larger lakes can accommodate more cottages. The technique of forcing a regression described by Draper and Smith (1968, page 175) produced somewhat better results. This entailed regressing cottager effort on numbers of cottages first, then regressing the residuals on lake area. An alternative and simpler approach proposed here is to divide the total cottager angling effort for the summer by the number of cottages on the lake and then regress the resulting effort per cottage ratio on the area of the lake (Fig. 10).

As can be seen, there is a great deal of variability in effort per cottage on lakes less than 1,500 ha in area, but the marked decrease in effort per cottage with increase in lake area is also evident. The equation for this line is:

$$\log_{10}E_{sc}/N = 1.576 - 0.000148(A) \quad (13)$$

where E_{sc}/N is the summer cottager fishing effort on the lake in terms of angler-hours $cottage^{-1}$ and A the lake surface area

in ha. Here r = 0.746 with 42 d.f. and P <0.01. The square of r indicates that about 56% of the lake-to-lake variation in effort per cottage could be accounted for by differences in lake area. To get the total angler-hours ha^{-1} summer^{-1} of effort, E_c, multiply E_{tc}/N by the total number of cottages and divide by the area of the lake.

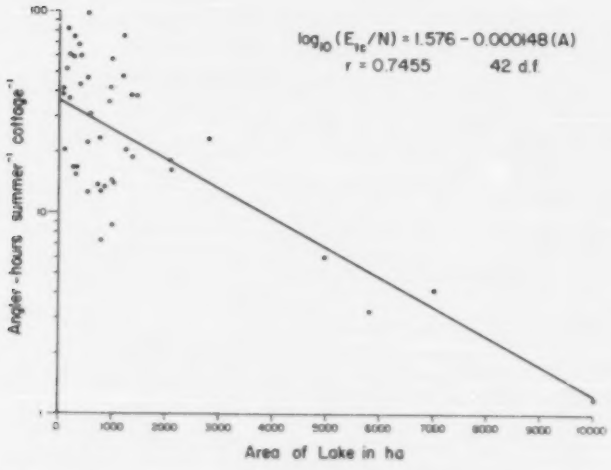

Figure 10. Relation between summer angling effort by cottagers, the area of the lake, and the number of cottages on it; corresponding to Equation (12).

3.2.4 SUMMER ANGLING EFFORT BY NONCOTTAGERS

In theory, one ought to be able to develop an equation relating the angler-hours of effort by noncottagers to the area of the lake and the number of accommodation units in the lodges, campsites, etc., which would be analogous to Equation (13). In practice, adequate information on such accommodation is much more difficult to obtain than the numbers of cottages. It is also very difficult to estimate what fraction of the noncottage anglers arrive on the lake through marinas or public launching ramps. Consequently, an indirect approach was taken by regressing the logarithm of noncottager effort on the logarithm of cottager effort, on the assumption that a lake which is more popular with the latter group is likely to be more popular with the former. The correlation is significant (r = 0.728, 36 d.f., P <0.01) and the least squares fit is:

$$\log_{10}E_n = 1.004(\log_{10}E_c) - 0.0575$$

or

$$E_n = 0.876(E_c)^{1.004} \qquad (14a)$$

where E_n is the angler-hours ha^{-1} summer^{-1} by noncottagers and E_c the angler-hours ha^{-1} summer^{-1} by cottagers.

However, since neither cottager nor noncottager effort is measured without error, and since the relation appears to be an interdependence rather than a dependence of one variable on the other, the "geometric mean regression" described by Ricker (1973) may be more appropriate here. For this regression (Fig. 11), the sum of squares of the deviations is minimized in both the vertical and horizontal directions, and the equation for the line is:

$$\log_{10}E_n = 1.204(\log_{10}E_c) - 0.286$$

or

$$E_n = 0.518(E_c)^{1.204} \qquad (14b)$$

Notice that the sum of E_n, estimated from Equation (14b) and E_c from the preceding section, is an estimate of the total summer angling E_s by cottagers and noncottagers combined. It can be inserted into Equation (11), together with the appropriate MEI, to get an estimate of the total summer yield for all anglers.

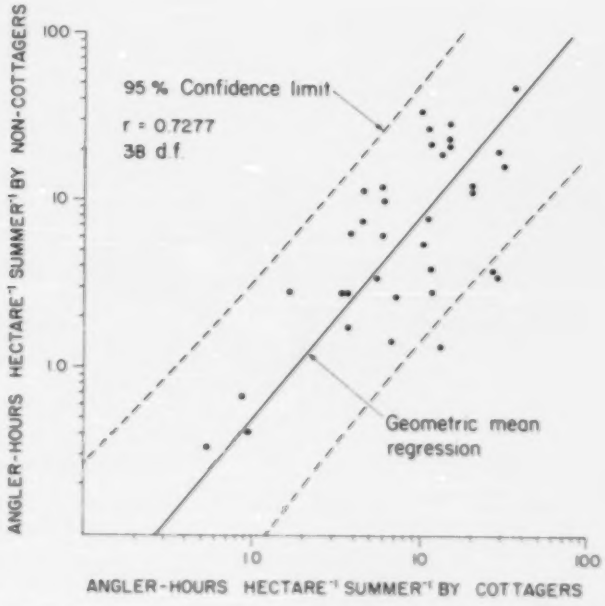

Figure 11. Relation between summer angling effort by noncottagers and summer effort by cottagers. See Equation (14b).

3.2.5 EXCESSIVE SUMMER HARVESTS

As noted earlier, total summer angling yields exceeded the MSY_c in 13 of the 56 fisheries listed in Table 2a, b and c. Total summer angling efforts on these heavily fished lakes ranged from about 3 to 147 angler-hours ha^{-1} summer^{-1}. Six (Big Hawk, Miskwabi, Percy, Esson, Bella and Rebecca) were lake trout lakes with MEIs less than 6 mg L^{-1} m^{-1}.

Up to this point, the net productivity model has been developed solely in terms of summer angling, because many of the study lakes are subject to summer angling only. This is also true of many other lakes in the Province to which the model might be applied. However, for any lake where winter angling is permitted, it must be taken into account as part of the total stress on the fishery.

3.2.6 PREDICTION OF WINTER ANGLING EFFORT

Here again, the predictive equation must be derived indirectly, because many of the winter anglers cannot be identified with points of origin on the lakeshores. Many come from nearby villages, others come for a day's fishing from cities a considerable distance away. Consequently, it was postulated that fisheries which are more favoured by summer anglers would also be more attractive to winter anglers or vice versa, and the

logarithm of total winter effort was regressed against the logarithm of total summer effort (Fig. 12). The correlation was found to be significant ($r = 0.731$, 20 d.f., $P < 0.01$) and the geometric mean regresson line is:

$$\log_{10}E_w = 1.315(\log_{10}E_s) - 0.438$$

or

$$E_w = 0.365\ (E_s)^{1.315} \qquad (15a)$$

where E_w is the total angler-hours ha^{-1} $winter^{-1}$, and E_s the total angler-hours ha^{-1} $summer^{-1}$ by cottagers and noncottagers combined. The corresponding least square fit is:

$$\log_{10}E_w = 0.962(\log_{10}E_s) - 0.0910$$

or

$$E_w = 0.811\ (E_s)^{0.962} \qquad (15b)$$

Although some authors have reported that winter angling may be more effective than summer angling, and may take a larger proportion of small, immature lake trout, the situation in the present study is not clear (see following section). Therefore, in the absence of consistent evidence to the contrary, an angler-hour of winter effort is considered to be equivalent to an angler-hour of summer effort in this report, and E_w is added directly to E_s to obtain the total effort for the year for lakes where winter angling is allowed. This sum can then be inserted into Equation (11) to get an estimate of the total annual yield.

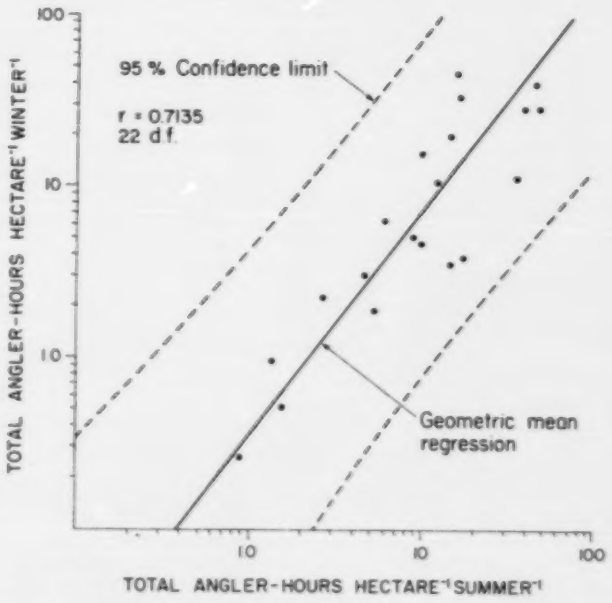

Figure 12. Relation between winter and summer angling efforts by cottagers and noncottagers combined. See Equation (15a).

Table 3a. Type and orgin of anglers interviewed in the Net Productivity Study creel censuses during the *summer of 1977.*

Name of lake	No. of anglers interviewed	Day trippers			Campers			Cottagers			Commercial guests			
		A	B	C	A	B	C	A	B	C	A	B	C	D
Bernard	317	15.5	8.2			15.5	0.6	1.6	40.7	0.6		15.3	1.3	0.3
Doe	1286	7.0	3.2	0.5	0.5	13.2	1.9	0.2	29.9	4.1		32.2	7.4	
Joseph	421	3.8	7.6	1.4		2.9		2.9	63.4	4.3	0.2	11.6	1.9	
Kawagama	545	0.6	4.2			7.0	0.9	0.6	78.3	3.1		2.9	0.7	1.7
Lake of Bays	407	1.0	2.2			0.7	2.7		69.0	7.9		6.6	3.7	6.1
Muskoka	209	16.7	6.2		1.0	5.7	1.4	10.5	56.5	0.5		0.5	1.0	
Pickerel	545	4.9	1.3			0.7		0.7	40.7	2.0		49.5		
Rosseau	412	5.8	4.4		1.0	6.8	1.7	4.1	53.6	5.1		12.6	4.8	
Skeleton	472	14.2	3.4	0.4		4.9	3.2	0.4	61.0	2.1		4.0	2.1	4.2
Boshkung	421	1.7	8.1					0.7	62.0	2.7		22.1		2.6
Dalrymple	1577	0.1	1.3			20.0	1.9		37.5		0.2	28.3	10.0	0.7
Esson	517	9.7	5.8			1.0			72.9		0.6	9.3	0.8	
Four Mile	486	0.8	1.4						91.8	1.9		0.6		3.7
Gull	256	1.4	10.5			10.9			53.1			9.8	14.5	2.0
Haliburton	387	1.6	2.1					5.7	85.3			4.9	0.5	
Head	544	2.2	15.1			2.0			76.5	0.9		0.6		2.7
Kashag	1221	2.5	3.7	0.4	0.1	30.7	1.6	23.6				31.4	3.9	2.0
Kennisis	503	4.4	2.4		0.4	4.2	0.4	0.8	73.4	0.4		13.7		
Miskwabi	481	6.0	22.2			6.0		0.8	54.9			10.0		
Redstone	396	13.6	11.9		0.3	5.6	1.3	1.5	55.6			10.4		
Twelve Mile	320	1.3	4.1			0.9	0.9	0.3	79.7	1.5		8.5	1.9	0.6

A = % local residents
B = % Ontario residents from outside district
C = Other
D = Unidentified

3.2.7 PECULIARITIES OF WINTER FISHERIES

Winter angling on the Net Productivity Study lakes differs from summer in that it is carried out by a somewhat different group of anglers (Table 3a, b) who tend to concentrate on lake trout, although smelt, whitefish and ling are taken, incidently, on some lakes. According to a survey conducted by the Land Use Component of the Lakeshore Capacity Study during the summer of 1978, about 49% of the cottagers were interested in summer angling, but only 5% were concerned with winter angling. Moreover, the creel census records show that, on the average, cottagers account for 52% of the total summer angling effort, but only 14% of the total winter effort. Day-trippers and local residents play a greater part in the winter fishery than in the summer angling. However, the more important question, from the standpoint of the net productivity model, is not "Who is doing the fishing?", but "What is the total weight of fish they are removing annually?".

In treating the winter angling effort as though it were equivalent to additional summer effort, we are probably underestimating the impact of winter angling on trout populations to some extent. Martin (1954) found that lake trout taken from 5 Algonquin Park lakes during the winter were generally smaller than those caught in summer, and that the winter angling exploited a high percentage of the immature stock. He suggests that this was due to differences between tackle, and methods used in summer and winter. In 10 of 12 lake trout lakes censused in the Net Productivity Study, the lake trout caught in summer were somewhat longer and heavier on the average than those caught in winter (Table 4).

Table 3b. Type and orgin of anglers interviewed in the Net Productivity Study creel censuses during the *winter of 1977.*

Name of lake	No. of anglers interviewed	Day trippers			Campers			Cottagers			Commercial guests			
		A	B	C	A	B	C	A	B	C	A	B	C	D
Bernard	111	87.4	7.2						5.4					
Joseph	99	59.6	23.2		11.1	6.1								
Kawagama	67	38.8	44.8					4.5	3.0			9.0		
Lake of Bays	90	60.0	27.8						12.2					
Muskoka	99	100.0												
Rosseau	42	97.6												2.4
Skeleton	170	93.5	5.9											0.6
Boshkung	719	20.9	32.4		1.3	2.6		1.4	13.2		0.3	27.4		0.6
Esson	62	27.4	16.1						56.5					
Gull	568	37.5	45.4			5.1			10.4			1.6		
Haliburton	20	30.0						50.0	20.0					
Kashag	53	67.9						32.1						
Kennisis	615	26.3	41.6				0.5	2.3	29.3					
Miskwabi	302	37.7	61.6						0.7					
Redstone	268	48.5	30.6			2.6			18.3					
Twelve Mile	152	42.8	25.0			20.4			9.9					0.7

A = % local residents
B = % Ontario residents from outside district
C = % from other provinces in Canada
D = Other

Table 4. Comparison of summer and winter averages for the length, weight and age of native and planted lake trout (combined) taken from Net Productivity Study lakes.

Name of lake	*Average length in mm		*Average weight in g		**Average age in years	
	Summer	Winter	Summer	Winter	Summer	Winter
Skeleton	†(85) 512.2	(250) 441.5	(91) 1247.8	(252) 817.0	(40) 7.4	(154) 6.8
Kawagama	(163) 425.5	(119) 419.9	(165) 791.0	(120) 711.1	(67) 6.6	(103) 6.5
Rosseau	(23) 578.8	(49) 537.8	(23) 2190.0	(52) 1849.5	(15) 8.4	(39) 8.8
Joseph	(74) 573.9	(203) 544.5	(74) 2298.1	(198) 1810.6	(34) 8.5	(170) 8.6
Lake of Bays	(14) 560.3	(28) 579.9	(13) 2153.3	(27) 2266.1	(4) 8.2	(20) 9.9
Bernard	(49) 641.9	(76) 676.6	(50) 2831.5	(75) 3320.5	(47) 10.2	(52) 10.4
Kennisis	(166) 482.4	(517) 384.7	(165) 1011.6	(502) 593.1	(74) 7.4	(237) 6.2
Redstone	(144) 407.8	(172) 393.1	(143) 683.4	(168) 644.7	(31) 6.7	(55) 6.5
Boshkung	(23) 409.3	(492) 377.2	(22) 779.0	(479) 621.4	(2) 8.5	(127) 5.9
Gull	(31) 377.8	(938) 349.4	(31) 554.3	(886) 481.9	(22) 6.1	(426) 5.6
Twelve Mile	(9) 419.9	(85) 410.4	(9) 999.5	(88) 849.5	(4) 5.7	(24) 5.8
Miskawbi	(155) 455.5	(203) 406.1	(153) 918.4	(202) 660.1	(57) 6.6	(36) 6.7

*Based on total lake trout sample for summers of 1975-79 and winters of 1976-79.
**Based on total lake trout sample for summers of 1977-78 and winters of 1977-79.
†The data in parenthesis are the total numbers of lake trout sampled.

Table 5a. Comparison between summer and winter angling by cottagers and noncottagers for native and planted lake trout combined on *Muskoka* Net Productivity Study lakes.

Name of lake	**MSY_c kg $ha^{-1}yr^{-1}$	Year	Angler-Hours $hectare^{-1}$ summer	winter	total	Yield in kg ha^{-1} summer	winter	total	$Yield_{lt}/MSY_c$
Skeleton	1.52	75	3.86			0.107			
		76	2.11	2.79		0.142	0.255		
		77	3.23	3.53		0.524	0.229		
		78	3.03	12.86		0.501	0.986		
		79		9.16			0.372		
		Average	3.06	7.08	10.14	0.318	0.460	0.778	0.51
Joseph	1.60	75	1.79			0.177			
		76	0.80	1.29		0.157	0.111		
		77	0.91	1.17		0.238	0.099		
		78	1.01	4.26		0.140	0.734		
		79		3.18			0.398		
		Average	1.13	2.47	3.60	0.178	0.335	0.513	0.45
Kawagama	1.64	75	3.08			0.234			
		76	3.03	1.28		0.245	0.117		
		77	3.88	1.12		0.328	0.041		
		78	3.27	3.11		0.380	0.224		
		79		3.48			0.257		
		Average	3.31	2.25	5.56	0.297	0.160	0.457	0.28
Lake of Bays	1.60	75	0.53			0.046			
		76	0.37	0.76		0.027	0.023		
		77	0.32	0.48		0.032	0.005		
		78	0.33	1.46		0.027	0.100		
		79		0.98			0.069		
		Average	0.39	0.67	1.06	0.033	0.049	0.082	0.05
Rosseau	1.77	75	0.34			0.030			
		76	0.30	0.42		0.031	0.012		
		77	0.37	0.28		0.041	0.004		
		78	0.69	0.84		0.095	0.151		
		79		0.95			0.203		
		Average	0.42	0.62	1.04	0.049	0.092	0.141	0.08
Bella	1.93	75	17.14			0.506			
		76		3.91			0.743		
		77		3.33			0.348		
		Average	17.14	3.62	20.76	0.506	0.545	1.051	0.54
Bernard	2.03	75	1.09			0.153			
		76	1.44	2.72		0.267	0.314		
		77	2.06	1.86		0.172	0.181		
		78	3.32	4.12		1.093	0.431		
		79		5.11			0.966		
		Average	1.98	3.45	5.43	0.421	0.473	0.894	0.44
Muskoka	2.11	76	0.35			0.036			
		77	0.06	0.30		0.007	0.006		
		78		0.22			0.016		
		79		1.64			0.141		
		Average	0.20	0.72	0.92	0.021	0.054	0.075	0.03
Pevensey	2.43	76	16.54	10.80	27.34	0.671	0.360	1.031	0.42

*Arranged in ascending order of MSY_c.

**Calculated from Equation (4): $MSY_c = 1.4(MEI)^{0.45}$.

Ryder and Johnson (1972) have suggested that lake trout swim in close schools during winter and may be more vulnerable to the anglers at that time. Hence, one might expect the number of lake trout caught per angler-hour of effort during winter to be higher than the number caught in summer. That this is the case for some of the lakes in the present study in some years can be seen in Table 5a and b. A regression of winter catch per unit effort (CUE_w) on catch per unit effort for the preceding summer (CUE_s), for the summer of 1975 through the winter of 1979, gives the line:

$$CUE_w = 0.0316 + 0.679(CUE_s) \qquad (16)$$

with r = 0.6358 and 44 d.f. Hence, the catch per unit effort tends to be higher in winter than summer for fisheries at the lower end of the summer CUE range, but lower in winter than summer for fisheries with higher summer CUE values. Why this should be the case is not known at present.

Table 5b. Comparison between summer and winter angling by cottagers and noncottagers for native and planted lake trout combined on *Haliburton* Net Productivity Study lakes.

Name of lake	**MSY_c kg $ha^{-1}yr^{-1}$	Year	Angler-Hours $hectare^{-1}$ summer	winter	total	Yield in kg ha^{-1} summer	winter	total	$Yield_{lr}/MSY_c$
Halls	1.55	76	17.87	19.95	37.82	0.419	0.524	0.943	0.61
Kennisis	1.63	75	12.45			1.428			
		76	12.09	9.74		1.180	0.989		
		77	4.66	23.25		0.458	1.326		
		78	6.52	13.78		0.743	1.618		
		79		5.92			0.411		
		Average	8.93	13.18	22.11	0.952	1.086	2.038	1.25
Boshkung	1.85	75	9.00			0.272			
		76	5.04	42.09		0.487	1.655		
		77	1.89	54.30		0.026	2.115		
		78	1.72	49.11		0.076	1.622		
		79		37.43			1.145		
		Average	4.41	45.73	50.14	0.215	1.634	1.849	1.00
Big Hawk	1.88	75	29.17			2.405			
		76	0.90			0.487			
		Average	15.03		15.03	1.45		1.45	0.77
Mississagua	2.09	75	11.40			0.561			
		76	7.92			0.179			
		77		3.56			0.388		
		Average	9.66	3.56	13.22	0.370	0.388	0.758	0.36
Haliburton	2.17	75	6.06			0.227			
		76	2.77			0.090			
		77	2.56			0.249			
		78	2.90			0.293			
		Average	3.57		3.57	0.215		0.215	0.10
Drag	2.22	75	5.30			0.114			
		76	3.37	3.66		0.093	0.199		
		77		5.67			0.112		
		Average	4.33	4.66	8.99	0.103	0.155	0.258	0.12
Redstone	2.40	75	18.61			1.410			
		76	11.68	9.44		0.589	0.631		
		77	6.11	15.26		0.313	0.809		
		78		6.26			0.645		
		79		4.05			0.146		
		Average	12.13	8.75	20.88	0.771	1.329	2.10	0.55

(continued on next page)

Name of lake	**MSY_c kg $ha^{-1}yr^{-1}$	Year	Angler-Hours hectare^{-1} summer	winter	total	Yield in kg ha^{-1} summer	winter	total	$Yield_{it}/MSY_c$
Mountain	2.41	76		22.74			0.280		
		78	3.68			0.000			
		79		18.11			0.197		
		Average	3.68	20.42	24.10	0.000	0.238	0.238	0.10
Gull	2.44	75	2.58			0.030			
		76	1.92	21.15		0.024	1.139		
		77	1.77	36.38		0.135	2.024		
		78	2.35	32.27		0.139	2.144		
		79		30.53			1.566		
		Average	2.15	30.08	32.23	0.082	1.468	1.550	0.63
Miskwabi	2.49	75	52.34			7.129			
		76	26.19	20.32		4.719	2.458		
		77	15.87	69.53		2.054	8.379		
		78	26.15	29.21		4.197	1.925		
		79		29.61			1.295		
		Average	30.14	37.173	67.31	4.525	3.514	8.039	3.23
Twelve Mile	2.59	75	9.28			0.066			
		76	11.32	42.49		0.697	1.232		
		77	3.03	56.67		0.178	2.229		
		78		31.56			1.228		
		79		30.76			0.694		
		Average	7.88	40.37	48.25	0.314	1.346	1.660	0.64
Percy	2.63	78	16.57			1.368			
Kashagawigamog	2.72	75	7.29			0.252			
		76	3.44	1.92		0.244	0.017		
		77	2.83	3.90		0.073	0.049		
		78	2.28	3.52		0.111	0.107		
		Average	3.96	3.11	7.07	0.179	0.058	0.237	0.09
Esson	3.47	75	35.04			3.602			
		76	37.48			4.375			
		77		28.48			1.343		
		Average	36.26	28.48	64.74	3.99	1.343	5.331	1.54

*Arranged in ascending order of MSY_c.
**Calculated from Equation (4): $MSY_c = 1.4(MEI)^{0.45}$.

3.2.8 IMPACT OF WINTER ANGLING ON NET PRODUCTIVITY STUDY LAKES

The contribution of winter angling to the total impact was most notable for lakes in the Haliburton region. The winter effort on Boshkung, Gull, Twelve Mile and Mountain Lakes was from 2 to 6 times the summer figure, while for Miskwabi and Redstone Lakes, both the summer and winter efforts were very high (columns 4 and 5, Table 2a and b) and, in contrast, winter efforts on lakes in the Muskoka region were about equal to, or less than, the summer effort. When the winter harvests are added to the summer, 16 of the net productivity lakes appear to be harvested at or above the respective MSY_c (last column, Table 2a, b and c).

On the basis of annual yields, the most heavily exploited lakes are Miskwabi, Percy and Long in the Haliburton region, and Hodson in the Muskoka region, with yields from 1.4 to 4.6 the MSY_c.

3.2.9 ANGLING PRESSURE, MEAN AGE OF CATCH AND SPECIES MSY FOR LAKE TROUT

If a yield in excess of the MSY_c estimated from Ryder's MEI formula does indeed represent overexploitation, one might expect to find related symptoms in the size and/or the age composition of the catches. Some evidence that the average age of native lake trout caught decreases with increasing angling pressure can be seen in Fig. 13. Although the exact form of

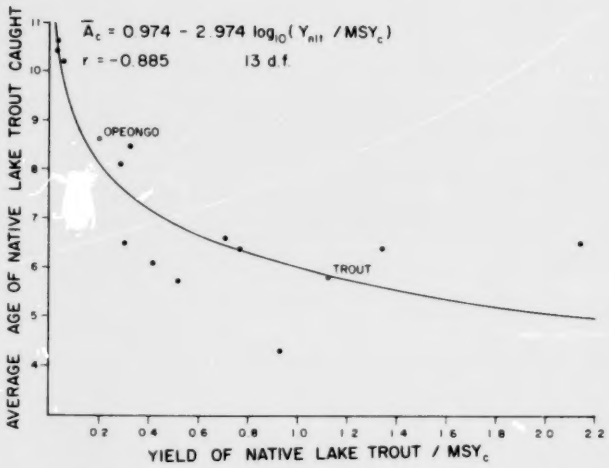
$\bar{A}_c$ = 0.974 - 2.974 $\log_{10}$(Y_{nlt} / MSY_c)
r = -0.885 13 d.f.
OPEONGO
TROUT
AVERAGE AGE OF NATIVE LAKE TROUT CAUGHT
YIELD OF NATIVE LAKE TROUT / MSY_c

Figure 13. Decline in the average age of native lake trout caught as anglers take an increasing fraction of the community maximum sustained yield, MSY_c. Opeongo and Trout are examples of lakes which are fished at or near the MSY_c and overfished respectively.

this relation is not certain from the present data, a least square fit of average age of native lake trout caught, A_c, on the logarithm of the ratio yield of lake trout Y_{nlt}, to MSY_c, gives the line:

$$A_c = 0.974 - 2.974\log_{10}(Y_{nlt}/MSY_c) \qquad (17)$$

with r = 0.885, 13 d.f. and P <0.1. The solid data points in the figure are for Net Productivity Study trout lakes fished both summer and winter. The open data points for Lake Opeongo and Trout Lake are shown as examples of lake trout fisheries exploited at maximum sustainable yield and overexploited, respectively. The Lake Opeongo fishery, which is conducted in summer only, has been censused for over 40 years (Martin and Fry 1973; B. Shuter, pers. comm.). From 1942 to 1979 angling effort has increased more or less continuously, but the catch has remained fairly constant at about 0.4 kg ha^{-1} yr^{-1} from the mid-sixties on. There has been some change in character of the fishermen over the years; many of the anglers in recent years being more casual and less efficient than those in earlier years. However, the angling pressure appears to havae reached the stage where it is limiting recruitment, and current catches are probably close to the maximum sustainable yield. In contrast, Trout Lake, Minnesota is reported by Schumacher (1961) to exhibit symptoms of overfishing.

If we assume that, in the case of lake trout fisheries, the size and age composition of the catch is reasonably representative of the composition for the trout population in the lake, and that lake trout usually mature at 6 to 7 years (Scott and Crossman 1973)[2], then an average age of harvest less than 6 or 7 years indicates that few mature fish are being left to spawn. Kawagama among the Muskoka lakes, and Boshkung, Gull, Kennisis, Miskwabi, Redstone and Twelve Mile among the Haliburton lakes, show this symptom, Table 4 and 6.
The lake trout fisheries of Kennisis and Miskwabi Lakes, represented by the two points farthest to the right in Fig. 13, may still be in what is called the "fishing up" stage (Ricker 1975; Regier and Loftus 1972). That is, there may still be very large and old trout remaining from years when exploitation of these fisheries was lighter than at present. There have been cottages on the south side of Kennisis Lake for many years but, during the past two decades, there has been a mark-

[2] Samples of lake trout gonads and corresponding size data were collected from some of the Haliburton lakes in our study, by W. Wilson, District Biologist. These were analysed by Dr. J. Casselman and E. Heczko, and the results support this assumption.

Table 6. Average yield and age of native and planted lake trout taken from Net Productivity Study lakes during the summers and winters of 1977-78, compared with yields and ages of native lake trout from Lake Opeongo, Trout Lake and Bone Lake. Note that age determinations for fish from the Net Productivity Study lakes were begun in 1977.

[1]Name of lake	MSY_c in kg $ha^{-1}yr^{-1}$	kg $ha^{-1}yr^{-1}$ all lake trout	% native lk. trout no.	% native lk. trout wgt	kg $ha^{-1}yr^{-1}$ native lake trout	Yield native lk. trout/MSY_c	Average age of catch all lake trout	Average age of catch native lk. trout	[2]Yield of all species
Muskoka/Bracebridge District									
Skeleton	1.52	0.78	59	54	0.42	0.28	7.1	8.1	1.34
Joseph	1.60	0.52	97	98	0.51	0.32	8.7	8.5	0.84
Kawagama	1.64	0.50	99	99	0.50	0.30	6.5	6.5	0.87
Lake of Bays	1.64	0.09	64	68	0.06	0.037	9.7	10.4	0.21
Rosseau	1.77	0.12	35	51	0.06	0.033	8.7	10.6	0.45
Bernard	2.03	0.52	33	32	0.17	0.084	10.2	10.2	1.23
Haliburton District									
Kennisis	1.63	2.45	96	96	2.35	1.44	6.5	6.4	2.32
Boshkung	1.85	2.08	59	69	1.43	0.77	5.8	6.4	2.65
Redstone	2.40	1.69	100	100	1.69	0.70	6.6	6.6	1.54
Gull	2.44	1.83	97	70	1.28	0.52	5.6	5.7	1.96
Miskwabi	2.49	9.60	63	56	5.34	2.14	6.7	6.5	11.40
Twelve Mile	2.59	1.94	40	56	1.09	0.42	6.0	6.1	3.26
From the literature									
Opeongo	1.72		100	100	0.4	0.23		8.6	?
Bone	2.15		100	100	1.97	0.92		4.3	?
Trout[3]	2.52		100	100	2.80	1.11		5.8	?

[1]Arranged in ascending order of MSY_c
[2]As in Table 2a, b and c.
[3]Minnesota (Schumacher 1961)

ed development on the north shore. Similarly, there was limited access to Miskwabi until about 10 years ago and little, if any, development. Under continued heavy angling, the average age of lake trout catch from these two lakes may drop, and the regression line may have to be refitted accordingly.

If one considers that Y/MSY_c is a measure of fishing pressure or intensity, then Fig. 13 resembles Fig. 17.7 of Beverton and Holt (1957). The latter figure, derived on *a priori* grounds, relates the mean age of commercial catches to the fishing mortality, which is in turn a product of the fishing intensity and a constant. An analogy between Fig. 13 and the approach taken by Abrosov (1969) can also be seen if one plots the difference between average ages at capture and at maturity against Y/MSY_c on double logarithmic paper.

Apart from any implication as to the effects of heavy fishing on spawning stocks, a decrease in the mean size of trout caught can be interpreted as a loss of quality in the fishery: the anglers would be catching fewer trophy fish than previously.

3.3 SPECIES MSY VERSUS COMMUNITY MSY

Fig. 13, and the foregoing observations on the Lake Opeongo fishery, suggest a means of relating the maximum sustainable yield for native lake trout, MSY_{nlt}, to the community maximum sustainable yield, MSY_c. For Lake Opeongo, the MEI and MSY_c are 1.57 mg $L^{-1}m^{-1}$ and 1.72 kg $ha^{-1}yr^{-1}$, respectively (SPOF Working Group 12 Report, March 1982). If the current average yield of 0.4 kg $ha^{-1}yr^{-1}$ is taken as the MSY_{nlt} as argued above, then $MSY_{nlt} = (0.4/1.72)MSY_c = 0.23MSY_c$, or approximately $0.2MSY_c$.

It is intended that this age structure-fishing pressure approach to estimating maximum sustainable yields for individual species be applied to other fish species, eventually. In the meantime, an alternative method for partitioning the MSY_c estimated from Ryder's MEI model has been suggested by Adams and Olver (1977). On examining catch statistics from 70 Ontario commercial fisheries, which appear to be withstanding current fishing pressures, they found that the annual yields of walleye amounted to $0.3MSY_c$ on the average. This approach has now been extended to obtain estimated MSY values for smallmouth bass, whitefish and northern pike in the SPOF Working Group 12 Report (Ontario Ministry of Natural Resources 1982) and the lake trout and walleye data have been revised to $0.25MSY_c$ and $0.32MSY_c$ respectively.

3.3.1 ALLOWABLE YIELD VERSUS MSY

Recently, Larkin (1978) has argued that, while the maximum sustained yield is a useful first approximation of the potential fish production for a body of water, it would be unwise to try to exploit the fishery at that level. For one thing, a fishing pressure sufficient to take an MSY_c made up of several species of fish may actually have a greater impact on some of the species than others. Even in single species fisheries some stocks may be more affected by the fishing pressure than others. Exploitation of the full MSY_c may not provide a sufficient margin of safety in the event of weak year classes (Doubleday 1976; Sissenwine 1978). It is recommended that fisheries be managed to take some fraction of the MSY_c which can be termed the allowable yield.

3.4 CONFIDENCE LIMITS ON PREDICTIONS FROM THE MODEL

Ideally, one ought to have data from a different set of lakes located in the same areas as the original set chosen for the Net Productivity Study creel censuses, with which to test the predictive capacity of the model. However, since an adequate set of such data is not available at present, we are obliged to take the approach of comparing the yields which were prorated from the creel census data and used to develop the model with the yields which were ultimately predicted from the model. This can be done by regressing the logarithm of the yield prorated from the creel census on the logarithm of the yield obtained on solving the successive regression equations in the model (see Table 7 and Fig. 14).

The solid line in Fig. 14 was fitted by least squares and depicts the general relation between the observed yields (i.e. those prorated from the creel census) and yields estimated from the Net Productivity Model. The formula for it is:

$$Y_{cc} = 1.129(Y_m)^{0.640} \qquad (18)$$

where Y_{cc} is the yield from the creel census and Y_m the yield from the model. The $r = 0.740$ with 34 d.f. and is significant at $P = 0.01$, as one would expect. The dashed lines in Fig. 14 represent the confidence limits on the estimate of an individual yield. They take the form:[3]

$$\log_{10}CL(Y_{cc}) = 0.179 + 0.640(\log_{10}(Y_m/1.577)$$
$$\pm 0.473(1 + 1/36 + (\log_{10}(Y_m/1.577))^2/5.323)^{0.5} \qquad (19)$$

According to this regression analysis, if the estimated angling yield for a particular lake is, say, 0.3 kg $ha^{-1}yr^{-1}$, the actual (creel census) yield will lie between 0.16 and 1.6 kg $ha^{-1}yr^{-1}$ in 95 cases out of 100, and will most likely be in the neighbourhood of 0.5 kg $ha^{-1}yr^{-1}$. On the other hand, if the estimated yield is 3.0 kg $ha^{-1}yr^{-1}$, the actual yield would centre on 2.0 kg $ha^{-1}yr^{-1}$ but could be as low as 0.7 or as high as 7.0 kg $ha^{-1}yr^{-1}$. Hence, the model tends to underpredict for low yields and overpredict for high yields.

That the confidence band on individual estimates from the model is so broad is not surprising, in view of the considerable scatter of data points about the several regression lines which go together to make up the Net Productivity Model (see Figs. 7, 8, 10, 11 and 12). Moreover, the confidence limits given here are probably somewhat narrower than those we would obtain on comparing the yields estimated from our model with yields from creel censuses on a different set of lakes. While the width of the confidence band may be disconcerting on first consideration, it serves as a reminder of the inherent variability of ecological and sociological data. For a recent and extensive discussion of the relationship between prediction from the calibration of ecological models and problems involved in determining the reliability of predictions, see Beck (1981).

With the information given here, the planner has 3 options, namely: (1) to use the regression line to adjust the yields

[3] Based on the formula:

$$CL(Y) = Y + bx \pm t_{0.05}Sy.x\,(1 + 1/n + x^2 \Sigma x^2)^{0.5}$$

As given, for example, in Steel and Torrie (1960), page 175.

estimated from the model to get an idea of what the fishing pressure is likely to be "on the average"; (2) to use the lower confidence limit to see what the least pressure might be; and (3) to use the upper limit to find the "worst case" situation.

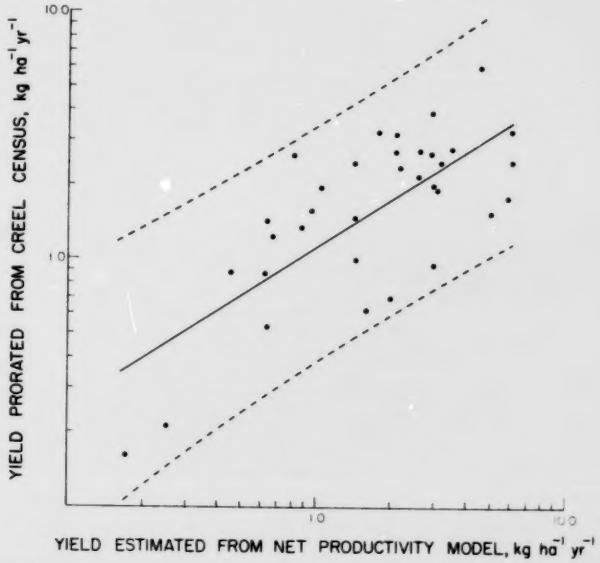

Figure 14. Relation between angling yields prorated from the Net Productivity Study creel censuses and those examined from the net productivity model. The solid line is the regression line, while the dashed lines are the upper and lower 95% confidence limits on individual estimated yields.

3.5 CONTRIBUTION OF PLANTED LAKE TROUT

Planted fish constituted 37% to 67% of the lake trout sampled on Bernard, Lake of Bays, Rosseau, Skeleton, Boshkung, Miskwabi, and Twelve Mile Lakes during 1977-1979 (Table 6). In contrast, planted fish made up 4% or less of the lake trout catches from Joseph, Kawagama, Gull, Kennisis, and Redstone Lake. Since Lake Joseph has not been stocked for over a decade, the 4 marked lake trout recorded there were probably migrants from Lake Rosseau or else native lake trout which had suffered accidental fin loss. The absence of marked lake trout in catches from Redstone Lake may also have been due to the lack of plantings in recent years. The low recoveries of stocked lake trout from Kawagama, Gull, and Kennisis Lakes seem to indicate lack of survival and/or recruitment of recent plantings.

The average age of planted lake trout in catches from the Muskoka lakes ranged from 6.7 to 10.1 years, whereas it was 4.9 to 6.5 years for lake trout from the more heavily fished Haliburton lakes. Since lake trout mature at 6 to 7 years on the average, the planted trout may make a contribution to the spawning stocks in some of the Muskoka lakes. However, the plantings seem to be exploited largely on a put-and-take basis in the Haliburton lakes, with only a small fraction surviving to maturity.

Generally, both planted and native lake trout recruit into the anglers' catches at age 3 or 4 in the Net Productivity Study lakes. This compares with the age at recruitment reported for other lake trout waters in the Province (Martin and Fry 1973; Olver 1968, 1971, 1972) and indicates that, although fisheries in our study area may be threatened by overexploitation, shoreline disturbance, acid rain, and other factors, there may have been some successful spawning and recruitment in the past 3 or 4 years. A possible exception is the Lake Bernard fishery where the youngest lake trout sampled were 7 or 8 years old.

The extent to which planted lake trout may divert fishing pressure from native stocks is not clear at present. However, it could be argued that, since the angler is allowed by fishery regulations to have only a certain number of fish in his or her possession each day, every planted fish caught corresponds to a native one which must be left in the lake. That some large, old lake trout are still appearing in catches from Miskwabi, the most heavily fished lake trout lake in this study, may be due partly to the fact that about 35% of the total catch of lake trout consists of planted fish.

Table 7. Comparison between average yields obtained from the prorated creel census data (Y_{cc}) and yields estimated from the Net Productivity model (Y_m).

Lake	MEI	No cott.	Y_{cc}	Y_m	Log_{10}* (Y_{cc}/Y_m)
Big Hawk	1.92	90	1.92	1.04	0.26627
Boshkung	1.86	281	2.65	2.83	−0.02854
Brady	8.67	58	2.77	3.45	−0.09534
Dalrymple	73.75	395	2.41	3.10	−0.10934
Davis	7.80	126	2.45	6.00	−0.38899
Drag	2.78	274	0.68	1.96	−0.45975
Esson	7.52	99	5.94	4.49	0.12154
Four Mile	16.00	410	1.91	3.08	−0.20752
Glamor	7.59	106	3.88	2.85	0.13399
Gull	3.45	410	1.96	2.97	−0.18050
Haliburton	2.64	438	0.62	1.52	−0.38945
Head	30.57	239	3.15	2.07	0.18234
Kashagawigamog	4.38	491	1.52	4.94	−0.51188
Kennisis	1.40	510	2.32	2.16	0.03103
Mississagua	2.43	217	0.93	2.89	−0.49241
Mountain	3.36	215	1.74	5.78	−0.52138
Redstone	3.33	150	1.54	0.95	0.20980
Twelve Mile	3.93	228	3.26	5.94	−0.26057
Bella	2.04	80	2.68	2.03	0.12064
Bernard	2.28	229	1.23	0.57	0.33403
Eagle	5.08	97	1.41	0.53	0.42494
Joseph	1.34	1109	0.84	0.45	0.27107
Kashe	6.32	492	2.14	2.56	−0.07783
Kawagama	1.42	433	0.87	0.62	0.14713
Lake of Bays	1.43	1595	0.21	0.25	−0.07572
Muskoka	2.50	4799	0.16	0.17	−0.02633
Peninsula	5.22	288	1.48	1.44	0.01190
Pevensey	3.41	37	1.67	2.33	−0.14464
Pickerel	4.07	77	2.59	0.80	0.51016
Rebecca	4.43	56	2.45	1.39	0.24615
Rosseau	1.68	1543	0.45	0.41	0.04043
Sand	1.53	191	0.98	1.39	−0.15179
Skeleton	1.21	386	1.34	0.86	0.19261
Sweny	2.79	37	2.68	2.57	0.01820
Three Mile	8.00	356	3.21	1.76	0.26099
Vernon	2.83	232	0.53	0.62	−0.06812

*Mean $\log_{10}(Y_{cc}/Y_m) = -0.0185$ and standard deviation = 0.2682.

4 SUMMARY AND CONCLUSIONS

4.1 APPLICATION OF THE MODEL IN A PLANNING CONTEXT

To apply the net productivity model in a lakeshore planning situation, one needs to know the area and mean depth of the lake; the midsummer total dissolved solids concentration; the existing number of cottages on the lake; the proposed number of new cottages; whether there is public access; and whether there is winter angling. One also has to decide on what the allowable yield is to be, based on the criteria discussed under SPECIES MSY VERSUS COMMUNITY MSY and ALLOWABLE HARVEST VERSUS MSY.

With this information in hand, the planner has the option of determining: (1) whether a proposed number of new cottages is likely to generate too much angling pressure for the fishery to sustain, or (2) what total number of cottages might be put on the lake without giving rise to excessive angling pressure.

For Option 1, proceed as follows:

Step 1. Divide the total dissolved solids by the mean depth, insert the resulting MEI into Equation (2) (i.e. Ryder's MEI formula), and solve for the MSY_c. If the lake has a prime lake trout fishery, and it is desired to exploit it at the same level as Lake Opeongo, set the allowable yield of native lake trout at 0.2 MSY_c.

Step 2. To estimate the summer angling effort by cottagers in angler-hours ha^{-1}, solve Equation (13), multiply the result by the total number of cottages on the lake (existing + proposed) and divide by the area of the lake. If there is little or no public access to the lake, negligible angling by noncottagers, and no winter fishery, skip to Step 5a.

Step 3. If there is public access and significant angling by noncottagers, insert the summer effort by cottagers obtained in Step 2 into Equation (14b) and solve for the angler-hours ha^{-1} $summer^{-1}$ expended by noncottagers. Add the result to that obtained from Step 2 to get the total summer effort by cottagers and noncottagers combined. If there is no winter angling, skip to Step 5b.

Step 4. If there is a winter fishery, insert the total summer effort calculated in Step 3 into Equation (15a) and solve for the total angler-hours ha^{-1} $winter^{-1}$ by cottagers and noncottagers combined. Add the result to the total summer effort obtained in Step 3 to get the total angler-hours $ha^{-1}yr^{-1}$ by all anglers. Then go to Step 5c.

Step 5a. Insert the summer effort by cottagers obtained in Step 2 into Equation (11), together with the MEI for the lake in question, and solve for the summer yield for cottagers.

Step 5b. Insert the total summer effort by cottagers and noncottagers calculated in Step 3 into Equation (11), together with the MEI for the lake in question, and solve for the summer yield for cottagers and noncottagers combined.

Step 5c. Insert the total angler-hours $ha^{-1}yr^{-1}$ derived in Step 4 into Equation (11) and solve for the annual yield for cottagers and noncottagers combined.

Step 5d. For the remote possibility of a combined summer and winter fishery by cottagers only, one would insert the summer effort by cottagers obtained in Step 2 into Equation (15a) and solve for the winter effort by cottagers. The result would then be added to the summer effort to get the total angler-hours $ha^{-1}yr^{-1}$ by cottagers. This in turn would be inserted into Equation (11), together with the MEI, to obtain the annual yield for cottagers only. However, this may be an overestimate, since the cottagers in our study area expressed relatively little interest in winter angling. This model is not designed to deal with the case where the angling is entirely by noncottagers.

Step 6. At this point, one could make one or other of the adjustments to the estimated yield discussed under the section on CONFIDENCE LIMITS TO PREDICTIONS FROM THE MODEL, if one wished to be more precise.

Step 7. Compare the estimated yield from Step 5a, b, c, or d with the allowable yield selected in Step 1. If it is greater than the allowable yield, the proposed number of new cottages is likely to generate too much angling pressure. Notice that by carrying out Steps 1 through 5a, b, c, or d for the condition zero new cottages, one could determine whether the existing number of cottages posed a threat to the fishery. This information might be used by fisheries managers in regulating season lengths and catch quotas or deciding whether planting of hatchery fish are required.

For Option 2, the procedure is:

Step 1. Select the allowable yield as in Step 1 of option 1 and then repeat Steps 2 through 5 (or 6) for the existing number of cottages, half the existing number and twice the existing number in turn to obtain three estimated yields.

Step 2. Regress the logarithm of the number of cottages against the logarithm of the respective estimated yield and fit a line by least squares. Insert the allowable yield into the equation for this line as the independent variable, and solve for the corresponding allowable number of cottages. The procedure for carrying out the above calculations with a Hewlett-Packard H.P.33E pocket calculator is described in Appendix 1.

4.2 EXAMPLES OF OUTPUT FROM THE MODEL AND CAVEAT

To extrapolate beyond the range of the data from which the model was developed, whether the model be a single regression line or a combination of several lines, involves greater inaccuracies in prediction. The present net productivity model relates to lakes with MEIs ranging from about 0.6 to 82 mg $L^{-1}m^{-1}$, cottage numbers from 16 to 4,800, and areas from 90 to 10,500 ha (Table 1a, b and c).

Fig. 15 shows examples of allowable numbers of cottages predicted from the net productivity model for lakes of different area, MEI, angling regime (summer angling only versus summer plus winter angling), and two different species of fish (lake trout and walleye). The most conspicuous feature is, of course, the steep rise in allowable number of cottages with increase in area of lake. This is due primarily to the fact that the angler-hours per cottage decreases markedly with increase in lake area (Fig. 10). It is also partly due to the fact that the yield per angler-hour of effort decreases with increasing effort (Fig. 9b). On the other hand, a 6-fold increase in MEI (from 1.4 to 8.8) does not quite double the allowable number of cottages. Notice too, that the higher the MSY for the species of fish concerned, the higher will be the allowable number of cottages.

However, if it is decided that the fishery should not be exploited at full maximum sustainable yield, but that some margin of safety should be allowed, then the allowable number of cottages will be reduced. For exploitation at about 75% of maximum sustainable yield for lake trout or walleye, the allowable number of cottages would be reduced by about 30%.

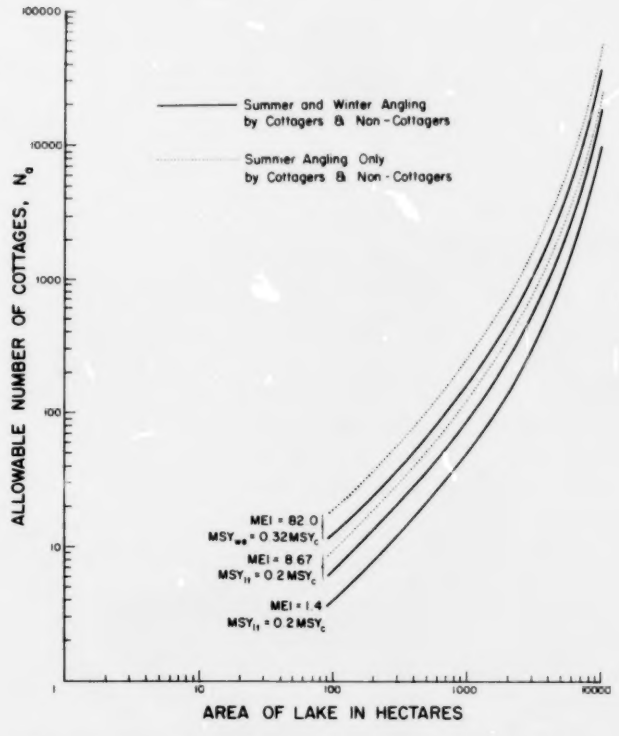

Figure 15. Examples of allowable numbers of cottages predicted from the net productivity model for lakes of different MEI, area, angling regime and 2 different species of fish, namely: lake trout and walleye. Based on allowable yields of $0.2MSY_c$ and $0.3MSY_c$ for the trout and walleye respectively.

Notice too, that the yield computations used to estimate the allowable cottage numbers plotted in Fig. 15 were not adjusted for the criteria set out under CONFIDENCE LIMITS TO PREDICTIONS FROM THE MODEL. Such an adjustment would, of course, modify the shape and location of the curves in Fig. 15 to a greater or lesser extent, depending upon whether one of the confidence limits or the regression of observed on estimated yield were used as the criterion.

4.3 RELATION TO OTHER COMPONENTS OF THE LAKESHORE CAPACITY STUDY

The flowchart in Fig. 16 indicates some of the paths by which energy and matter enter, flow through, recycle, and exit from the aquatic ecosystem. It is also intended to identify points at which the Net Productivity Study may be linked to other components of the Lakeshore Capacity Study. No attempt has been made to show all conceivable paths by which energy and matter might move from one level in the food chain to another: only those which seem most relevant to the present discussion are considered.

Notice that the box representing the game fish in this diagram has been subdivided into four parts according to the state of maturity and size of the fish. This allows us to indicate that, although angling pressure in general is spread over all sizes, it tends to concentrate on progressively smaller and younger fish as it increases. As initial "fishing up" or continued moderate angling pressure removes large fish from the lake, it reduces competition and predation. As a result, increased survival and accelerated growth of the remaining fish may come into play and compensate for the loss of biomass. If the angling pressure continues to increase, however, a point may be reached where removal of biomass may outstrip replacement.

The Net Productivity Component is linked to the Littoral Zone Component in at least three ways. First, any disturbance or destruction of the littoral zone which results in a significant loss of habitat for the bottom fauna or forage fish could lead to a reduced food supply for the game species. This, in turn, could lead to slower growth and reduced survival of these fish. Secondly, alteration of the littoral zone could reduce the amount of spawning or nursery grounds available to the game fish and possibly result in decreased production of their young. The third linkage would be through the destruction of weed beds and areas littered with rocks, stumps or tree trunks, which serve as cover or hunting grounds for adult game fish. Each of these effects tends to aggravate the problem caused by heavy fishing pressure, and it is conceivable that destruction of the littoral zone may pose the greater threat in some instances. On the other hand, cribbing associated with docks, may to some extent supplement the habitat available for bass and sunfish.

The relation between cottage development and phosphorus loading (Dillon and Rigler 1975) being dealt with by the Trophic Status Component may effect the net productivity in two ways. If the phosphorus load from additional cottage construction were to produce heavy blooms of phytoplankton and, if, on dying and decaying these blooms lowered the dissolved oxygen concentration in the hypolimnion (Cornett and Rigler 1979; Walker 1979; Welch and Perkins 1979) to less than 5 mg L^{-1}, the lake would be rendered unsuitable to a species such as lake trout, which seeks the deeper, cooler strata during summer. That such oxygen deficits can be

produced by discharge of urban sewage or industrial wastes into lakes, such as we are considering here, has been documented (Michalski and Conroy 1972; Michalski and Nicholls 1975). Whether these deficits can result from cottage development remains to be determined.

Alternatively, if the increased production of phytoplankton were to be exploited by the zooplankton and/or bottom fauna, energy and matter might be passed up the food chain and lead ultimately to increased production of game fish. The practice of adding organic or inorganic fertilizers to ponds to enhance production of carp and other warm water species has a long history in Europe and the Orient, but attempts to increase production of trout in Canadian waters have met with variable success (Langford 1948; Smith 1954). Reports from British Columbia and the State of Washington of increased salmon production in recent years, as a result of intentional or unintentional enrichment of lake waters, have been reviewed by Stockner (1979). He cautions that "For a variety of reasons..., treated lakes responded differently to fertilization, suggesting that extrapolation of results... could be erroneous and/or dangerous".

A possible clue as to which path the phosphorus may take is provided by recent work of Schindler (1977) and associates in the experimental lakes project in northwestern Ontario. He found that, when the ratio of nitrogen to phosphorus was about 14:1 by weight, the blooms resulting from fertilization were comprised of the unicellular green alga *Scendesmus*. In contrast, when the ratio of nitrogen to phosphorus was about 5:1, the blooms consisted of the nitrogen fixing bluegreen alga *Anabaena*. It is not clear to what extent zooplankton utilize bluegreen algae. Hutchinson (1967) cites a case where the cladoceran, *Daphnia*, decreased in number as a bloom of bluegreen algae reached its peak, and a case where another cladoceran, *Chydorus*, ate bluegreens. However, since most zooplankters are filter feeders, it seems likely that they would prefer the smaller diatoms, flagellates and unicellular green

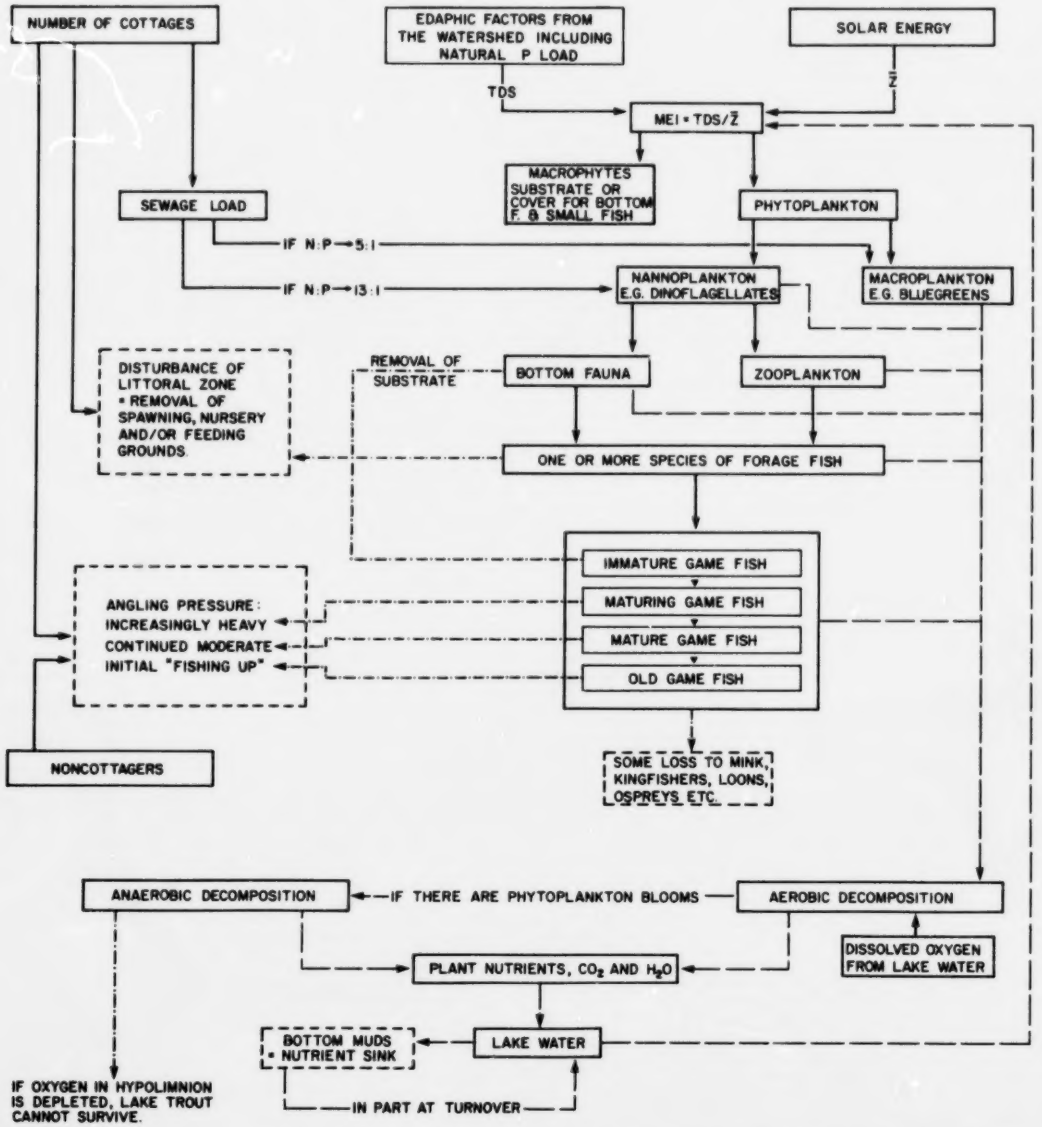

Figure 16. Flow chart for the net productivity model indicating linkages with other components of the Lakeshore Capacity Study. Solid lines designate energy and matter flowing into or through the system; dashed lines indicate energy and matter recycling; and interrupted lines indicate energy and matter being removed from the ecosystem. Rectangles with dashed boundaries are sinks.

algae, (which make up the nannoplankton) to the bluegreen algae which are usually bulky, colonial forms. The extent to which bottom fauna use bluegreen algae is also not clear. Davies (1980) reported that a greater emergence of Diptera was related to increased phytoplankton production resulting from the fertilization of one of the northwestern Ontario experimental lakes. Davies did not indicate which species of phytoplankton were involved. A possible switching mechanism, dependent on nitrogen to phosphorus ratios and a short-circuiting of phosphorus to the bottom muds via blooms of bluegreen algae, is shown in the flowchart.

Of course, the man-made phosphorus loading can have an impact other than on the fishery. If the concentration of phytoplankton anticipated from the development threatens to shift the chlorophyll content and the Secchi disc reading of water clarity, beyond the limits set by the Ministry of the Environment, this may be the factor restricting cottage and other development.

That there may be some loss of fish to mink, kingfishers and other piscivorous mammals and birds, is indicated near the bottom of the flowchart. Some authors have expressed concern over such losses in connection with production of Atlantic salmon smolt (Elson 1962) or plantings of young hatchery-reared trout (Fraser 1974), but their magnitude would be very difficult to measure. In a study of feeding biology of the common loon on oligotrophic lakes of the Canadian Shield, Barr (1973) observed that loons nested on lakes from about 9 to 6,000 ha in area and established territories averaging 72 ha in area. He estimated that a pair of loons rearing two offspring and occupying the territory for 6.5 months, remove 430 kg of food from that territory. To the extent that alteration of shoreline habitat reduces numbers of mammalian and avian piscivores, as demonstrated by the Wildlife Component of the Lakeshore Capacity Study (Euler, 1983) it tends to reduce this leakage. However, the writer does not believe that the number of game fish that might be saved would compensate for the loss in variety of wildlife. Moreover, as Barr (1973) points out, the loon preys mainly on yellow perch and, rather than being harmful to the game fisheries, may actually be beneficial in removing competition for food and space by less desirable species.

The loss to poachers could also be included here as something we can recognize but not quantify. The concerns of the Wildlife and Littoral Zone Components also overlap where clearing of cottage sites, grading, road building and such activities aggravate erosion and siltation.

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6. APPENDICES

APPENDIX A
CALCULATIONS USING A HP33E POCKET CALCULATOR

The following is the procedure for estimating the angling effort, angling yield and allowable number of cottages from the net productivity model with a HP33E pocket calculator. Similar programs can be developed for other calculators having the required functions.

OPTION 1

To determine whether a proposed number of new cottages, when added to the existing number, is likely to generate too much angling pressure, begin by entering and storing the prerequisite information:

Key in area of lake in ha and STO 1.
Key in total dissolved solids in mg L^{-1} and ENTER.
Key in the mean depth in m and divide to get the MEI. STO 2.
Key in the existing number of cottages and ENTER.
Key in the proposed number of new cottages and add. STO 3.

Then solve the successive equations in Steps 1 to 5.

Step 1. To calculate the allowable yield, Y_a, solve:
$MSY_c = 1.4(MEI)^{0.45}$...(2) as follows:
RCL 2, 0.45, fy^x, 1.4, X. Leave the result in the x-register.
If this is a lake trout lake, then: $Y_a = 0.2MSY_c$
0.20, X, STO 4.

Step 2. To estimate the summer angling effort by cottagers, E_c, in angler-hours ha^{-1}, solve:
$\log_{10}E_{tc}/N = 1.576 - 0.000148(A)$ ..... (13)
Then multiply E_{tc}/N by the total number of cottages (existing and projected) and divide by the area of the lake in ha.
RCL 1, .000148, X, CHS, 1.576, +, $g10^x$, RCL 3, X, RCL ,1 ÷, STO 5.
If there is no public access and no winter angling, skip to Step 5.

Step 3. If there is public access and significant fishing pressure by noncottagers, E_n, solve:
$E_n = 0.518(E_c)^{1.204}$ ..... (14b)
and add result to E_c, thus:
RCL 5, 1.204, fy^x, 0.518, X, RCL 5, +, STO 5.
Note that $E_c + E_n = E_s$, the total summer effort by cottagers and noncottagers combined. If there is no winter angling, skip to Step 5.

Step 4. To calculate the winter angling effort by cottagers and noncottagers combined, E_w, solve:
$E_w = 0.365(E_s)^{1.315}$ ..... (15a)
and add to E_s, to get the total effort for summer plus winter by all anglers, E_y, as follows:
RCL 5, 1.315, fy^x, 0.365, X, RCL 5, +, STO 5.

Step 5. To estimate the total annual (or seasonal) angling yield from the lake, solve:

$\log_{10}Y = 0.458(\log_{10}MEI) + 0.126(\log_{10}MEI)^2 + 0.728\log_{10}(E) - 0.834$ ..... (11)

and take the antilog.
E = E_c, E_s, or E_y, according to whether there is; (a) summer angling by cottagers only, (b) summer angling by cottagers and noncottagers, or (c) summer and winter angling by cottagers and noncottagers.
RCL 5, fLOG, .728, X, RCL 2, fLOG, STO 6, gx^2, .126, X, +, RCL 6, .458, X, +, .834, −, $g10^x$.

Step 6. The adjustment for one or other of the criteria given under CONFIDENCE LIMITS ON PREDICTIONS FROM THE MODEL could be made at this point, if desired.

Step 7. Compare the Y calculated in Step 5 with the Y_a from Step 1. If Y is greater than Y_a, there is a danger that the projected number of new cottages, when added to the existing number, will result in too much angling pressure.

OPTION 2

Step 1. To determine the total number of cottages, N_a, which might be constructed on the lakeshore without generating too much angling pressure, begin by carrying out Steps 1 through 5 (or 6) of Option 1. Copy down the yield, Y, estimated from Step 5.

Step 2. Halve the number of cottages used in Step 1 thus:
RCL 3, 0.5, X.
Then repeat Steps 1 to 5 of Option 1 and copy down the second estimate of Y from Step 5.

Step 3. Double the number of cottages used in Step 1 thus:
RCL 3, 2, X.
Then repeat Steps 1 to 5 of Option 1 and copy down the third estimate of Y from Step 5.

Step 4. Regress the logarithm of the number of cottages on the logarithm of Y, using the built-in function in the calculator thus:
Key in N, fLOG, ENTER
Key in Y, fLOG, Σ.
Repeat three times, then:
Key in Y_a, fLOG, f$\hat{y}$, g10^x. The result = N_a.

APPENDIX B

LIST OF SYMBOLS

A	Area of lake in ha.
A_c	Average age of native lake trout in anglers' catch. See Equation (17).
C	Total number of fish caught by anglers during the season or year, as recorded in the creel census. See Equation (6).
d	Number of days per season on which creel censuses were conducted. See Equation (6) and (7).
d'	Total number of days in angling season. See Equation (6) and (7).
d.f.	Degrees of freedom for statistical tests.
E'	Number of anglers per party multiplied by the number of hours fished up to time of interview, summed over the season. See Equation (6).
E_c	Angler-hours $ha^{-1}summer^{-1}$ of effort by cottagers = E_{tc}/N multiplied by the total number of cottages on the lake, N, and divided by the area of the lake.
E_n	Effort by noncottagers in angler-hours $ha^{-1}summer^{-1}$ estimated from Equation (14a) or (14b).
E_s	Total summer effort by cottagers and noncottagers combined = $E_c + E_n$ in angler-hours $ha^{-1}summer^{-1}$.
E_w	Winter angling effort by cottagers and noncottagers combined in angler-hours $ha^{-1}winter^{-1}$. See Equation (15a) or (15b).
E_y	Total effort for the year by cottagers and noncottagers combined.
E_{cc}	Effort in angler-hours $ha^{-1}season^{-1}$ prorated from the creel census data using Equation (7).
E_{tc}/N	Angler-hours of effort per cottage per summer estimated from Equation (13).
MEI	Morphoedaphic index = total dissolved solids content of lake water in mg L^{-1} divided by the mean depth of the lake in m.
MSY	Maximum sustained yield of fish in kg $ha^{-1}yr^{-1}$.
MSY_c	Maximum sustained yield for a fish community in kg $ha^{-1}yr^{-1}$. Matuszek (1978) and the present author equate this with the yield estimated from Ryder's MEI formula (Equation (2)).
MSY_{lt}	Maximum sustainable yield for lake trout only = approximately 0.2 MSY_c.
N	Proposed and/or existing number of cottages on the lakeshore.
P	Statistical probability.
P_n	The net productivity index in kg $ha^{-1}yr^{-1}$. It is the kg $ha^{-1}yr^{-1}$ of fish removed by the anglers divided by the kg $ha^{-1}yr^{-1}$ estimated from Ryder's MEI formula. See Equation (5).
R	Total number of fish released by the anglers during the season or year, as recorded in the creel census. See Equation (6).
t	Seasonal average of the hours spent on the lake per day by the census taker. See Equations (6) and (7).
t'	Total possible hours of fishing per day, averaged over season, for a given lake.
TDS	Total dissolved solids concentration in lake water in mg L^{-1}.
W	The mean weight of fish caught and kept by the anglers, for a given lake.
Y	The general symbol for the kg $ha^{-1}yr^{-1}$ or kg $ha^{-1}season^{-1}$ of fish removed from the lake by anglers.
$\hat{Y}$	General symbol used for a value estimated from any regression line. For example, Adams and Olver (1977) use it for the yield estimated from Ryder's MEI formula.

Y_a Allowable or capacity harvest. It is the maximum kg $ha^{-1}yr^{-1}$ which could be taken from the lake on a sustained basis without endangering the fishery.

Y_m The angling yield in kg $ha^{-1}yr^{-1}$ estimated from the overall net productivity model.

Y_{cc} Weight of fish caught and retained by anglers in kg $ha^{-1}yr^{-1}$ (or $season^{-1}$) prorated from the creel census data using Equation (6).

Y_{nlt} Angling yield of native lake trout only in kg $ha^{-1}yr^{-1}$ prorated from creel census data.

Z Mean (average) depth of lake in m.

APPENDIX C

GLOSSARY

adipose fin
A small, vestigial structure on the back of a trout, between the dorsal and caudal (tail) fins.

allowable yield
The maximum sustainable yield or some designated fraction thereof chosen to provide a margin of safety in setting fishery quotas. It is stated in kg $ha^{-1}yr^{-1}$.

allowable (or capacity) number of cottages
The maximum number of cottages which could be built around the lake without generating too much angling pressure and yields in excess of the allowable yield.

angler-hour
The angling effort expended by one angler in one hour.

bottom fauna
The community of snails, clams, crayfish, insect larvae, etc. which lives on the bottom of a lake, pond, or stream.

chemical stratification
A difference in concentration of dissolved oxygen, nitrates, phosphates and other chemical substances from the surface of a lake to the bottom, often giving a layered effect.

chlorophyll-a concentration
The concentration of green plant pigment in micrograms per litre. As it is relatively easy to extract and measure with precision, it is often used as a measure of the phytoplankton present.

cottage development
In this report, the measure of cottage development is simply the number of cottages on the immediate watershed.

cottager
Anyone who owns, rents, or stays as a guest at a cottage within the immediate watershed of the lake. Permanent residents on the lake are also classed as cottagers in this study.

creel
The traditional wicker basket in which an angler keeps his or her catch.

creel census
A record of the species, number and sizes of fish caught by anglers together with information on the time spent angling, etc.

creel census (roving)
A creel census conducted by interviewing the anglers on the lake while they are fishing, in contrast to interviews conducted when they come ashore.

edaphic factors
Chemical substances such as phosphates, nitrates, carbonates, etc., which leach into the lake from the soils on the watershed or come from upstream.

eutrophic
A term applied to a lake which has high concentrations of phosphorus, nitrogen, and other chemical substances and is, therefore, capable of supporting abundant plant and animal life.

fishing up
A well known phenomenon whereby the largest and oldest fish are selectively removed from a newly exploited fishery.

hypolimnion
The cold water mass in the deeper layers of a thermally stratified lake or pond (see Thermal stratification).

insolation
The amount and intensity of sunlight falling on the surface of the land or water.

lake morphometry
The shape of a lake basin, as characterized by the mean depth, shoreline development, etc.

lakeshore
In this report, this term refers to both waterfront and second tier lots.

lakeshore capacity
In this report, the term embraces the whole lake environment including the watershed, lake basin, lake water, and the associated plant and animal life.

mesotrophic
An intermediate state between oligotrophic and eutrophic.

MSY_c
The maximum weight of 2 or more species of fish which could be removed from a fish community without altering the kinds and sizes caught, i.e. the community maximum sustained yield.

MSY_{lt}
The maximum weight of lake trout which could be removed from the lake year after year without significantly altering the ages and sizes of lake trout caught, i.e. the maximum sustainable yield for lake trout.

macrophytes
Literally "large plants"; in this case, the rooted aquatic plants growing partly or wholly submerged on the littoral zone.

morphoedaphic index
The quotient of the total dissolved solids concentration of the lake water in milligrams per litre divided by the mean depth of the lake in metres. It is used as a measure of trophic status in Ryder's morphoedaphic index formula and in the present study.

native lake trout
Lake trout which occur naturally in the lake, as distinguished form those introduced by planting.

noncottagers
A day-tripper, lodge guest, camper, or anyone not staying at a cottage on the lake. Cottagers from other lakes are included in this category, in this report.

oxygen deficit
The difference between the concentration of dissolved oxygen required to saturate the lake water at ambient temperature and the observed concentration where the latter is the smaller value.

oligotrophic
A term applied to a lake having low concentrations of phosphates, nitrates and other plant nutrients and capable of supporting only limited plant and animal life.

photosynthesis
The process whereby plants convert carbon dioxide and hydrogen from the water into carbohydrates, using chlorophyll as a catalyst and sunlight as the energy supply. The carbohydrates supply energy to the plants as required and to the animals which feed upon them.

phytoplankton
A host of microscopic plants (algae) which drift about, grow, multiply, and carry on photosynthesis in the open (offshore) waters of the lake. They are a major part of the first link in the food chain (primary production) leading ultimately to the production of fish.

planted lake trout
Lake trout which were reared in a hatchery and then planted into the lake.

plant nutrients
Compounds of phosphorus, nitrogen, and other elements which serve as food for plants.

Secchi disc
A simple and rugged device for measuring water transparency. It is a metal disc about 20 centimetres in diameter, painted black and white in alternating quadrants, and suspended horizontally on a line marked off in half metres. In use, it is lowered until it disappears and then raised until it reappears: the average of the two depths being taken as the reading.

thermal stratification
A decrease in temperature from the surface to bottom of a lake or pond during summer, or an increase in winter. In summer, the lake is often divided into 3 zones; the epilimnion in the upper several metres, the hypolimnion below and the thermocline between.

trophic status
The capacity of a lake to support plant and animal life such as phytoplankton, zooplankton, bottom fauna, and fish.

yield
In this report, as in Ryder's MEI model, the term yield refers to the total weight of fish removed from the lake by fishermen divided by the area of the lake in question. It is stated as kg $ha^{-1}yr^{-1}$ or kg $ha^{-1}season^{-1}$ according to the nature of the fishery.

zooplankton
A host of microscopic animals (cladocerans, copepods and rotifers) which drift and swim about in the open waters of the lake and feed upon some of the phytoplankton.

APPENDIX D

SCIENTIFIC NAMES OF FISH

Lake whitefish	*Coregonus clupeaformis*
Rainbow trout	*Salmo gairdneri*
Lake trout	*Salvelinus namaycush*
Northern pike	*Esox lucius*
Muskellunge	*Esox masquinongy*
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
Yellow perch	*Perca flavescens*
Walleye	*Stizostedion vitreum vitreum*
Smelt	*Osmerus mordax*